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The Influence of Running Propellers on Airplane Characteristics

CLARK B. MILLIKAN

California Institute of Technology

Third Wright Brothers Lecture*

Introduction

THE subject matter of this lecture is peculiarly appropriate to the present occasion upon which we are gathered to honor the Wright Brothers. Although their contributions to aviation have covered a remarkably wide range of subjects and have dealt with very diverse branches of the art, the single feat for which they will always be remembered is their accomplishment, thirty-six years ago tomorrow of the first successful *power driven* flight of a man-carrying airplane. Gliding flights of considerable duration had previously been achieved by many experimenters but it was the brothers Wilbur and Orville Wright who first successfully equipped the heavier-than-air machine with a self-contained propulsive system and so created the airplane as we know it today. The Wrights' solution of the problem of transforming the shaft power of an engine into useful thrust for propelling an aircraft was based essentially on the use of the screw propeller, and theirs has remained the solution employed on every practical airplane constructed since 1903. The fundamental influence of the running propeller on airplane characteristics is clearly the overcoming of the airplane's drag by the propeller's thrust so as to make level or climbing flight possible. This primary influence was practically demonstrated by the Wright brothers' first flights.

It was early realized that running propellers might have effects on characteristics other than resistance to forward motion, such as stability, control, flying qualities, etc., and scattered wind-tunnel investigations on such questions began to appear in the technical literature at a relatively early date. However, until fairly recently these secondary effects of running propellers were in general relatively minor, so that the power-on characteristics of an airplane could be estimated from its power-off or gliding flight characteristics through the application of rough empirical correction factors.

In recent years this procedure has become increasingly unsatisfactory. Engine horsepowers have rapidly increased with a corresponding decrease in power loading. Multi-engined installations have been more widely used and wing-loadings have increased spectacularly. Thus the percentage of wing area affected by propeller slipstream and the slipstream velocity have both greatly increased, with the result that the modifications to airplane characteristics produced by running propellers have in many cases developed a fundamental importance. Indeed this change from "power-off" to "power-on" may often require serious modification in the overall proportions of an airplane designed for satisfactory power-off operation with a "margin of safety" based on past experience. For the past two years the author, together with other members of the GALCIT† staff, has been occupied with a number of investigations undertaken with the view of narrowing this "margin of safety" by furnishing information as to the nature and magnitude of these power-on effects. The material contained in the present paper has been developed during the course of these investigations.

I. Examples of Power-On Effects and General Conclusions

In this section a few typical examples are given showing the effects of power on certain aerodynamic characteristics which are importantly affected by the change from power-off to power-on operation. The results

* Presented before the Institute of the Aeronautical Sciences at Columbia University, New York, December 16, 1939. See Discussion, pages 103–106.

† Guggenheim Aeronautics Laboratory, California Institute of Technology.

were obtained during more or less routine wind-tunnel tests on models of contemporary multi-engined monoplanes. The author is much indebted to the Douglas Aircraft Corporation, the Lockheed Aircraft Corporation, and the North American Aviation Corporation, for permission to use these experimental data.* All of the results of this section were obtained during confidential tests so that model dimensions and details are not available. This fact, however, in no manner detracts from the significance of the curves as representative of typical effects to be expected with modern, high performance airplanes. The power-off curves are taken from conventional wind-tunnel tests on models without propellers. The power-on data were obtained with the same models equipped with driven propellers as described in section II. Figs. 1, 3, and 4 correspond to tests made at the GALCIT following the procedure outlined in section III, the power-on curves representing full rated power output of the engines under actual flight conditions. The data for Fig. 2 were obtained during tests in the University of Washington wind tunnel, the power-on curves corresponding to constant values of propeller V/nd.

Fig. 1 shows the influence of power on the static longitudinal stability of a model as indicated by the associated increment in pitching moment coefficient about an arbitrarily chosen C.G. position. It will be

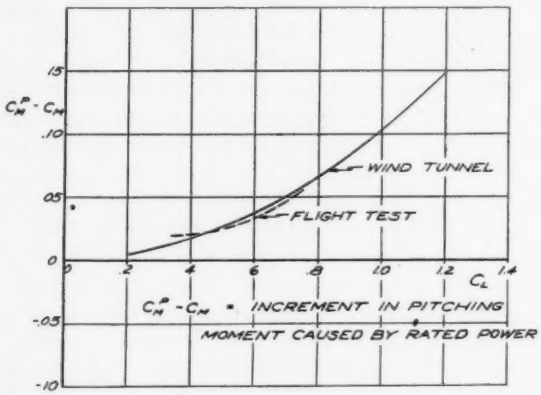

FIG. 1. Effect of rated power on pitching moments; wind-tunnel and flight test results.

observed that the limiting rearward C.G. position for neutral stability (as determined by the minimum value of $-dC_M/dC_L$) is moved some 15 percent of the m.a.c. forward by the change from the power-off to the power-on condition. This is not at all an unusual effect, several measurements with other models having indicated still larger stability changes. The magnitude is, however, large enough to cause considerable consternation to the designer who has laid out his airplane for satisfactory power-off stability without considering the possible influence of running propellers. The flight test results included in the figure show definitely that the power effect predicted by the wind-tunnel tests was in this case very satisfactorily substantiated in flight.

Fig. 2 presents wind-tunnel results dealing with the influence of power on elevator effectiveness as well as on static longitudinal stability. It appears that in this

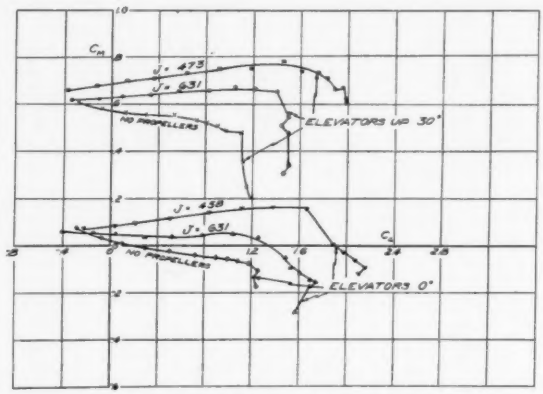

FIG. 2. Effect of running propellers on static longitudinal stability and elevator effectiveness; wind-tunnel test results.

example the change from power-off to power-on produces an increase in elevator effectiveness as well as a decrease in stability similar to that shown in Fig. 1. Fig. 2 also illustrates the large increase in $C_{L_{max}}$ which is always associated with the addition of running propellers.

Fig. 3 gives results of directional stability measurements. The two characteristic features which appear

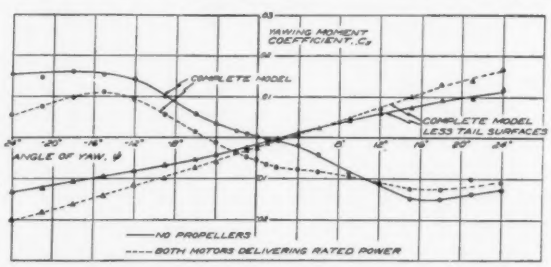

FIG. 3. Effect of rated power on yawing moments at angles of yaw; wind-tunnel test results.

are the moderate destabilizing effect of power when tail surfaces are not present and the complete lack of symmetry which the running propellers cause when the tail surfaces are in place. This lack of symmetry is presumably connected with the slipstream rotation.

Data pertinent to the problem of flight with one or more engines of a multi-engined airplane inoperative are given in Fig. 4. For the conditions corresponding to this test the rudder effectiveness is such as to furnish a satisfactory margin of control, and this effectiveness is not violently altered by the presence of the slipstream.

* Acknowledgment is also gratefully made of the assistance furnished by Douglas engineers who first undertook the development of models and testing technique for routine power-on wind-tunnel tests, and to the Lockheed and North American engineers whose contributions to the problems involved have also been very considerable.

In many cases, however, neither of these conclusions remains valid, and in fact this type of operation often imposes critical limitations on an airplane. Whenever this is true the importance of data analogous to those of Fig. 4 is very great.

The examples given above serve to emphasize the great influence which running propellers may have on the vitally important aerodynamic characteristics of an airplane. The problem of the airplane designer is to determine quantitatively the magnitude of these effects so that he may take them into account in laying out his airplanes. Unfortunately the data at present available are entirely inadequate for this purpose, so that the designer is forced to rely almost entirely upon his general judgment and experience, which in such a connection are only too often fallible. Three general lines of attack suggest themselves in the attempt to improve the situation:

(a) Theoretical analysis with the aim of setting up formulas which will satisfactorily give the effect of power for any specific airplane.

(b) Extensive basic research carried out systematically on models so simplified that all of the pertinent parameters may be varied through a range of values large enough to cover any anticipated requirements of the designer.

(c) The inclusion of tests with power driven, running propellers in the routine wind-tunnel testing of each new design. Such tests must duplicate the conditions of power operation for which the full scale airplane is designed.

Any exact and purely theoretical attack of the type (a) appears to be practically hopeless because of the complex nature of the phenomena involved and the great influence of interference effects which are extremely difficult to treat theoretically. Relatively crude and elementary theoretical analyses of the most important elements, supplemented by empirical data may, however, be of considerable use. Such a procedure dealing with the effect of power on lift and pitching moments is outlined later in section IV. The large amount of empirical material which is required if any such procedure is to furnish reliable results can probably best be furnished by supplementary investigations of the type (b). However the multiplicity of parameters involved and the expense of the tests required for the collection of an adequate body of data make it almost certain that such a program could be undertaken usefully only by a large governmental laboratory.

Even if programs of the types (a) and (b) could be fairly completely carried out it seems likely that ad hoc tests of the type (c) would also be desirable in the case of many new designs. For unless airplane design becomes far more standardized and uniform than has ever been the case in the past, the variations in the effects of power from model to model because of differences in detail design and local interferences will almost certainly remain large, and it is hardly conceivable that such differences will ever be amenable to generalized treatment. When consideration is taken of the length of time which must elapse before any satisfactory program of the type (a) or (b) can possibly reach the stage of furnishing useful and general information it becomes clear that if power-on effects must be determined for airplanes to be produced in the near future, procedure (c) gives the only practicable method. The examples of this section indicate the necessity of determining these effects. With the above considerations in mind work was started some years ago at the GALCIT on the development of equipment which would make practicable routine power-on wind-tunnel tests of new designs.

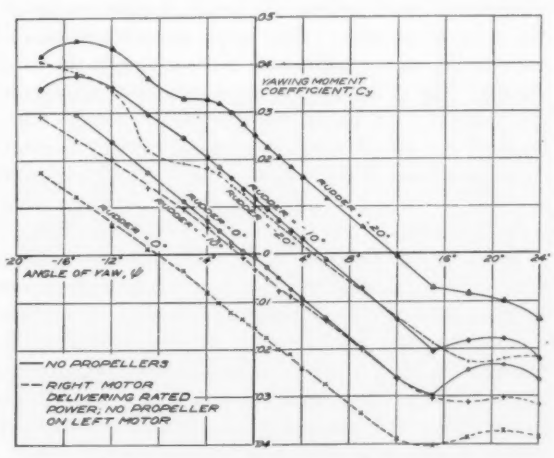

FIG. 4. Effect on yawing moments of single-engine operation with a bi-motored model having various rudder deflections; wind-tunnel test results.

II. GALCIT EQUIPMENT FOR POWER-ON WIND-TUNNEL TESTS

The fundamental problem in the making of routine power-on wind-tunnel tests lies in the supplying of power to the propellers of models which are of a size suitable for such investigation. In recent years, at least in the United States, most of the wind tunnels used for industrial testing have had working sections whose diameter was of the order of ten feet. Model spans of from six or seven to nine feet have accordingly become fairly standard for this purpose. The model propeller motors must therefore fit inside the fuselage or nacelles of models having about these dimensions. (The driving of propellers from motors outside the model is out of the question for tests of the type under consideration.) The problem is most difficult in the case of multi-engined models where the use of a central large motor in the fuselage driving the various propellers through gearing or hydraulic transmission has not yet proven practicable. The requirement in such cases is, then, for a motor delivering several horsepower at relatively high r.p.m. which must fit in the nacelle of a

multi-engined model with a wing span of the order of eight feet. Not only the diameter but also the length of such a motor is extremely limited. The solution to this problem was furnished by special high-powered induction motors developed by a Los Angeles firm* from somewhat similar motors driven by high-frequency alternating current and used for high speed small tools. The wind-tunnel motors used up to the present have been designed to operate on 3-phase current at frequencies up to 300 cycles. The smallest motors used deliver about 5 hp. at 18,000 r.p.m. and have an outside diameter of $3^3/_4$ in. and a length exclusive of propeller shaft of $6^5/_8$ in. Somewhat larger motors delivering up to 12 hp. have also been tested in complete wind-tunnel models. Still higher powers could be reached by water cooling which has not yet been employed. The propellers have duralumin blades either machined from bar stock or forged. Several sets of forging dies for such model blades have already been constructed by the Douglas Aircraft Corporation which is prepared to furnish blades of the sizes available. It is hoped that other companies will follow this practice which should eventually reduce the cost of model propellers very materially. Fig. 5 shows a typical motor-propeller assembly.

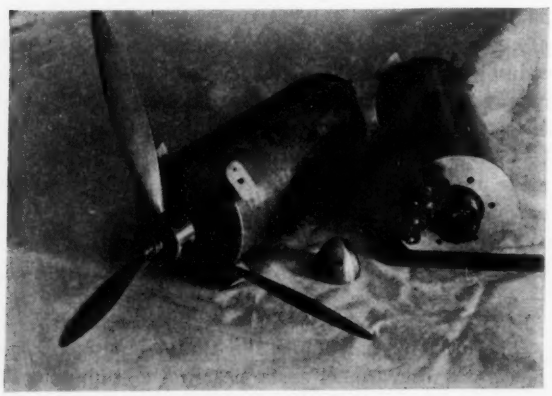

FIG. 5. Typical model motor-propeller assembly.

Power is furnished to the motors from a 20 hp. frequency converter driven by a d.c. motor. The output frequency is controlled between the limits of 40 and 300 cycles by varying the speed of the d.c. motor. The output voltage is roughly proportional to frequency and has a maximum value of 170 volts at 300 cycles. The maximum output current is 70 amperes. It should be mentioned that the amount of power available has on some occasions proven an inconvenient limitation and that a power source having two or three times the above capacity would be very desirable.

In view of the extreme dependence of power absorbed by a propeller on r.p.m. very accurate tachometric measurements were desired. Fig. 6 illustrates schematically the system adopted. In principle this consists in matching on an oscilloscope the alternating current from a magnetic pick-up, built around the motor shaft, against a saw-toothed current wave produced by a variable speed commutator whose rotational speed is counted over a six-second period by a Jaquet Indicator. The frequency of the input current to the motors is also determined with this apparatus which has proven entirely satisfactory.

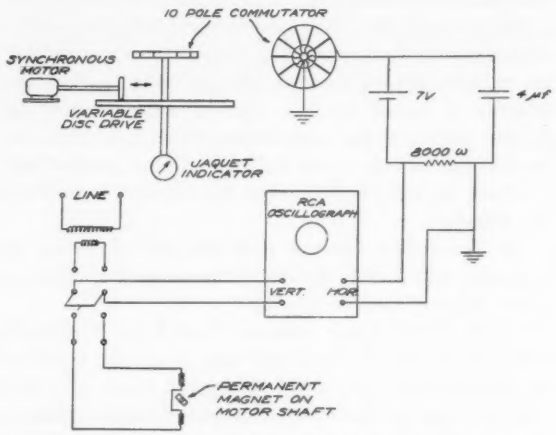

FIG. 6. Schematic diagram of tachometric system.

The method of measuring the power supplied to the motors is essentially determined by the fact that the tests must be suitable for routine operations. This practically eliminates the possibility of torque dynamometers mounted in the models and leads to the method of determining power by measurement of the electrical energy input to the motors. This in turn involves separate calibration of the electrical power input against shaft power delivered, which is accomplished with a specially designed dynamometer. The power input is measured on a three-phase precision wattmeter in conjunction with variable tap current and voltage transformers used to keep the meter readings as nearly full scale as possible. The same metering system is used during motor calibration and running in the wind tunnel. The dynamometer is essentially a high speed a.c. generator of which the electrical elements were built by the model motor manufacturer. It is water-cooled and has a maximum capacity of 50 hp. at 36,000 r.p.m. The motor torque is measured by a beam balance attached to the dynamometer stator. Fig. 7 shows the dynamometer with a motor set up for calibration. Fig. 8 gives the results of typical calibration tests on two motors for a bi-motored model. It will be noticed that the results for the two motors are indistinguishable, and it has been found that the motors in general hold their calibration practically perfectly as long as their ball bearings do not exhibit obvious evidences of abnormal friction or failure.

During a wind-tunnel test the motor speed control, tachometric instruments, and power measuring equip-

* Sawyer Electrical Manufacturing Company.

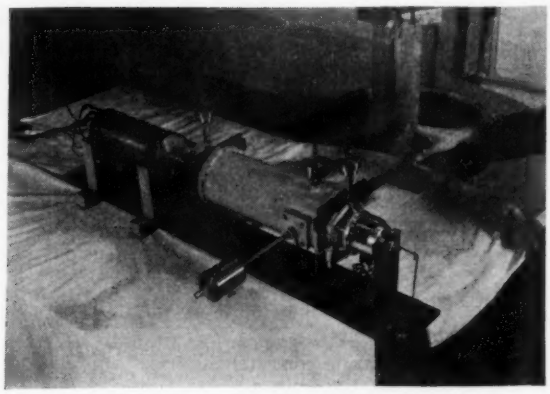

FIG. 7. Dynamometer set up for model motor calibration.

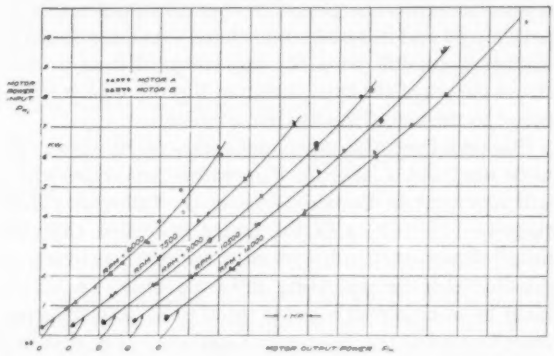

FIG. 8. Calibration results with two motors for a bi-motored model.

ment are all located at the control table beside the conventional wind-tunnel and model controls. One operator, in addition to the usual wind-tunnel crew, is required for all of the additional operations and measurements necessitated by power-on tests. Fig. 9 shows the control table arranged for such an investigation. The main metering panel is designed to permit power and speed measurements on each motor successively of a six-engined model.

FIG. 9. Control table and equipment for power-on wind-tunnel tests.

III. Suggested Operating Procedure for Routine Power-On Wind-Tunnel Tests

The majority of the wind-tunnel tests which have been made in the past with driven model propellers have followed some such procedure as the following: Conventional force and moment measurements were made at a series of constant values of propeller V/nd covering the range of interest, and the data obtained were later analysed to give results corresponding to specific engine operating characteristics, constant angle of climb,[1,2] etc. This procedure, while suitable for a basic research investigation, is extremely inefficient in connection with a routine wind-tunnel test where time and expense are of great importance. For with this procedure many more experimental observations must be made than are needed to specify the effects of power under the flight conditions which determine the design of the airplane in question. It is, therefore, essential to develop a testing procedure which will permit the determination of power-on effects for previously given power operation conditions of the prototype airplane.

In the development of this procedure it is found desirable to start with certain fundamental considerations on the basic question of reproducing full-scale power effects in the wind tunnel. The problem is to determine model engine and propeller operating characteristics which will correctly correspond to the full-scale operating characteristics. Since the principal effects of the change from "no propeller" to "power-on" operation are those due to the action of the slipstream, it is clear that the fundamental criterion should be the duplication by the model of the full-scale slipstream characteristics. Writing V_s = axial velocity in the slipstream, V = free-stream velocity, then, neglecting slipstream rotation, V_s/V should be made the same for model and full-scale conditions. If we write $V_s/V = 1 + 2\mu$ and assume that in the region of interest V_s has reached its maximum value downstream from the propeller disk, then the Froude momentum theory gives:

$$2\mu = \sqrt{1 + 8T_c/\pi} - 1$$

$$T_c = \text{Thrust}/\rho V^2 d^2$$

where

ρ = air density,
d = propeller diameter,
T_c = thrust coefficient.

Hence, neglecting slipstream rotation, model and full-scale slipstream conditions will be the same if T_c (model) = T_c (full scale). If the propellers are also geometrically similar (*e.g.*, have the same blade angle), then, aside from scale and compressibility effects, the model and full-scale slipstream relations, including rotation, will be identical. The problem of reproducing full-scale conditions is quite different when the full-scale propeller operates at constant blade angle than when it

operates at constant r.p.m., the reason being that model propellers always operate at constant blade angle; *i.e.*, controllable-pitch model propellers are not as yet available. However, before discussing the two cases individually, certain common aspects of the problem may be considered.

We shall use the subscript $(\ )_m$ to denote model conditions, full-scale conditions having no subscript. We assume that the model plane and propeller are geometrically similar to the full-scale prototypes, except possibly for propeller blade angle. Two scale factors are involved:

$$\lambda = L_m/L,\ \gamma = V_m/V$$

where L is a characteristic length of the plane, and V is the velocity of flight (V_m = wind-tunnel airspeed). λ is fixed for any one investigation, while γ may be varied during the test.

We are given three sets of data:

(a) Airplane thrust power characteristics: $P\eta(V)$* (cf. Fig. 10a). For constant-speed propeller operation we may also be given N and P;

(b) Model motor characteristics: $P_{m_i}(P_m,\ N_m)$ (cf. Fig. 10b);

(c) Propeller characteristics: $C_P(J,\beta)$, $C_T(J,\beta)$, $\eta(J,\beta)$ (cf. Fig. 10c);

where

P = b. hp. delivered to propeller,
η = propulsive efficiency,
P_{m_i} = power input to the model electric motor,
N = propeller r.p.m.,
C_P = power coefficient = $P/(\rho N^3 d^5)$ (using consistent units),
C_T = thrust coefficient = $T/(\rho N^2 d^4)$ (using consistent units),
$J = V/Nd$ (using consistent units),
β = propeller blade angle.

For the determination of test operating conditions it is assumed that the propeller characteristics apply to both model and full-scale conditions. As a result of the tests it is possible from the experimental data to construct curves of the type shown in Fig. 10c which correspond to the actual model characteristics.

Starting from the given data illustrated above, we must work out a laboratory operating procedure which will represent in the wind tunnel the full-scale conditions of Fig. 10a, with the added condition that the model slipstream conditions must approach as nearly as possible the corresponding full-scale ones, *i.e.*, $(T_c)_m$ must be as nearly as possible equal to T_c, and the same must be true of the slipstream rotations. The first step in this procedure is to convert the coordinate V of Fig. 10a into the corresponding wind-tunnel variable C_L. Assuming that the lift equals the weight for the full-scale airplane, the relation between these quantities is given by

$$C_L = (2/\rho_0)l_w/(\sigma V^2) = 391 l_w/(\sigma V_{m.p.h.}{}^2) \qquad (1)$$

where l_w = wing loading (lb./ft.^{2}).

The conversion of the other coordinate $P\eta$ into a variable usable in the wind tunnel requires separate discussions for fixed-pitch and constant-speed propellers.

A. *Model Power Determination for Fixed-Pitch Full-Scale Propellers*

We must first determine the propeller operating conditions from Fig. 10a. For this purpose a rather unorthodox power coefficient denoted by C_{Vd} is useful. This is derived from the thrust power coefficient defined in terms of velocity and diameter, $P\eta/(\rho V^3 d^2)$, and is closely related to T_c. It is more convenient than the latter for the present purpose because of its more restricted range of values.

$$\left.\begin{aligned} C_{Vd} &= 0.0239\left(\frac{\sigma d^2}{P\eta}\right)^{1/3} V \\ &\qquad (d = \text{ft.},\ P = \text{hp.},\ V = \text{m.p.h.}) \\ &= J/(\eta C_P)^{1/3} = 1/T_c{}^{1/3} = J^{2/3}/C_T{}^{1/3} \end{aligned}\right\} \qquad (2)$$

From the definition of Eq. (2) curves of C_{Vd} vs. J may

* Throughout the paper an expression of the form $y(x)$ is to be read "y as function of x." The parenthesis is also employed in the conventional manner but this should lead to no confusion since the context will serve to distinguish without difficulty between the two usages.

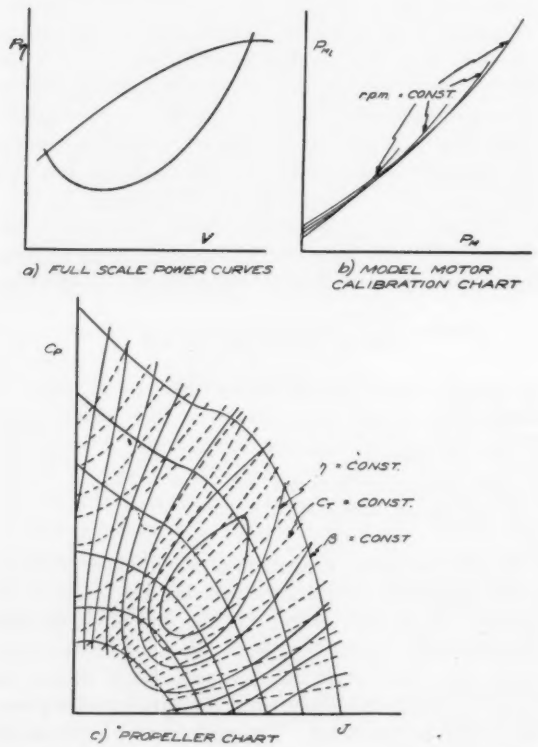

FIG. 10. Typical data furnished for a power-on wind-tunnel test.

be constructed for constant β or C_P, using conventional propeller data (*e.g.* Fig. 10c). For a given fixed-pitch propeller it is only necessary to calculate a single C_{Vd} vs. J curve for the blade angle in question.

Using Eq. (2) C_{Vd} vs. V is determined from the given $P\eta$ vs. V relation of Fig. 10a. Then J vs. V is obtained from the C_{Vd} vs. J curve for the given β, and η vs. V is obtained from the standard propeller chart. This gives $N(V)$ and $\eta(V)$ or, from (1), $N(C_L)$ and $\eta(C_L)$. If the variation of engine r.p.m. with velocity has already been estimated so that $N(V)$ is given, the C_{Vd} calculation is unnecessary and may be omitted.

Now if, for a fixed-pitch propeller, we put $J_m = J$ then not only the thrust coefficient but also the slipstream rotation and thrust loading over the propeller disk are identical for model and full scale, neglecting scale and compressibility effects. Hence the natural condition to impose is:

$J_m = J$ (operating criterion for fixed-pitch propellers (3)

from which follows immediately

$$V/Nd = V_m/N_m d_m = (\gamma/\lambda)V/N_m d$$

Hence

$$N_m = \frac{\gamma}{\lambda} N(C_L) \tag{4}$$

From this relation an operating chart of N_m vs. C_L for constant values of γ could be drawn up; this would be satisfactory, if the tests were carried out at constant values of the speed ratio γ. However, the normal operating technique is to carry out the measurements at constant values of

$$q = (\rho_m/2)V_m^2 = \text{wind-tunnel dynamic pressure.}$$

This means that γ is a function of C_L given (from Eq. (1)) by

$$\gamma = \sqrt{\frac{\sigma q}{\sigma_m l_w} C_L} \tag{5}$$

(where q and l_w are in the same units), so that N_m may be expressed as a function of C_L and q

$$N_m = \frac{1}{\lambda}\sqrt{\frac{\sigma q}{\sigma_m l_w}}\sqrt{C_L}\, N(C_L) \tag{6}$$

In general to obtain the greatest accuracy the operating q would be chosen as large as possible to reach the values of C_L desired without exceeding the limiting r.p.m. of the model motor. However, it often occurs that, although a given r.p.m. lies below the upper motor limit, the electrical power available is insufficient to give this r.p.m. with the blade angle chosen. It is, therefore, desirable to investigate the model power as an alternative operating parameter.

We have seen that the C_{Vd} propeller curve leads to $N(C_L)$ and $\eta(C_L)$. The latter gives $P(C_L) = P\eta/\eta(C_L)$. Now, instead of applying the scale factor to N, we may apply it directly to P. For $P = \eta C_{Vd}{}^5 \rho V^3 d^2$ and, retaining the basic condition $J_m = J$ so that $(\eta\, C_{Vd}{}^5)_m = (\eta C_{Vd}{}^5)$,

$$P_m = (\sigma_m/\sigma)\lambda^2\gamma^3 P(C_L)$$

or, using Eq. (5),

$$P_m = \lambda^2 \sqrt{\sigma/\sigma_m}(q/l_w)^{5/3} C_L{}^{5/3} P(C_L) \tag{7}$$

Eqs. (6) and (7) may be represented graphically on a single chart having the form of Fig. 11 which constitutes a complete operating chart for the assumed full-scale power conditions. It is clear that either N_m or P_m

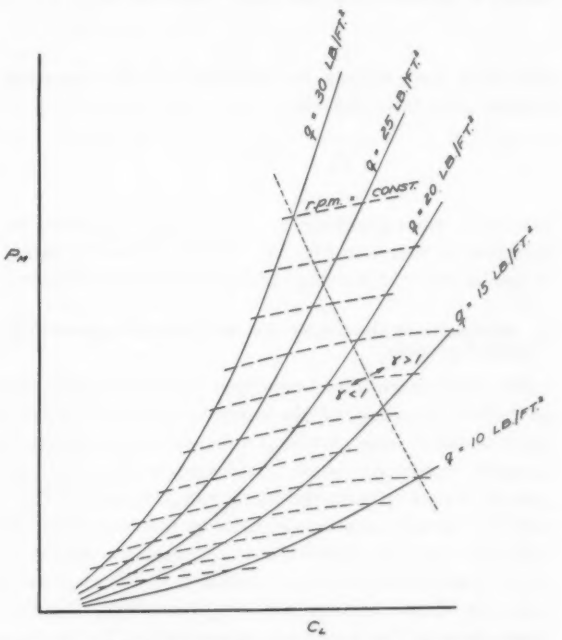

FIG. 11. Complete model operating chart including power and r.p.m.

may be taken as the parameter in terms of which the model power plant is operated. Where the data of Fig. 10b are available from an accurate motor calibration, the parameter P_m is much the more satisfactory one, for the model propeller may not be an accurate model of the full-scale prototype and neither may follow at all accurately the available propeller charts, Fig. 10c. This means that $N(C_{Vd})$ may not be accurately known, so that Eq. (6) may be considerably in error since $N(C_L)$ is not exact. However, the propeller operating conditions will normally be such that $\eta(C_{Vd})$ or $\eta(J)$ are fairly flat curves; *i.e.*, even if the propellers do not correspond accurately to the charts, still η will be given with relatively little error. Hence $P(C_L)$ will be quite accurate, as will P_m given by Eq. (7). For this reason it is much more satisfactory to set the model operating characteristics from P_m rather than from N_m. N_m should be used only as a check, unless the power calibration of the motor is poor while the tachometric system for measuring N_m is good.

One factor which has not yet been mentioned, but which must be kept in mind, is propeller tip speed. In general, the prototype power plant is designed so that the tip speeds are somewhat below those at which appreciable tip-speed losses occur. In such cases it is sufficient to require the model tip speeds to be equal to or less than the full-scale values. The two are connected by the relation:

$$\frac{V_m(\text{tip})}{V(\text{tip})} = \gamma \tag{8}$$

Hence, in general, we should apply the restriction

$$\gamma \leqq 1$$

This limit may readily be indicated on the operating diagram, for, from Eq. (5),

$$C_L = \frac{\sigma_m l_w}{\sigma q}\gamma^2$$

The curve corresponding to $\gamma = 1$ may, therefore, be indicated as shown in Fig. 11. If it is desired, a family of similar curves for other values of γ may be included.

B. *Model Power Determination for Constant-Speed Full-Scale Propellers*

For modern airplanes equipped with constant-speed propellers, the range of blade angles covered in normal flight is fairly large, while if take-off is considered, it becomes extremely large. It therefore becomes impossible to cover even the flying range in a model test with the model blade angle equal to the corresponding full-scale one. In other words, J_m and β_m cannot be given exactly their full-scale values, and the model and full-scale slipstreams cannot be geometrically similar. Since the axial slipstream component is usually the most important, we, therefore, take as the model operating criterion, $T_{c_m} = T_c$, or from Eq. (2)

$$(C_{Vd})_m = C_{Vd} \tag{9}$$

In general, it appears that, with this condition satisfied, the complete flying range may usually be covered with a single model blade angle without introducing unduly large differences in model and full-scale slipstream rotation, thrust distribution, etc. If the take-off range is to be covered, it is probable that two or more model blade settings will have to be used to avoid undesirable blade stalling.

We start with an airplane power curve, but in this case N is given so that the power curve may be of either of two types. If, as is almost always the case, it is a power-available curve, then P, as well as $P\eta$, is known and will generally be independent of speed. In this case we immediately obtain C_P and J as functions of V. From the propeller chart, Fig. 10c, β, η, and C_T are then obtained, the latter determining C_{Vd} from Eq. (2). The full-scale, constant-speed propeller characteristics are now presented graphically as indicated by the solid curves of Fig. 12. A velocity V_0 is chosen in the center of the region of greatest interest and the fixed-pitch propeller setting is taken as that corresponding to β_0, so as to reproduce all of the full-scale propeller conditions at V_0. From the propeller chart, Fig. 10c, sets

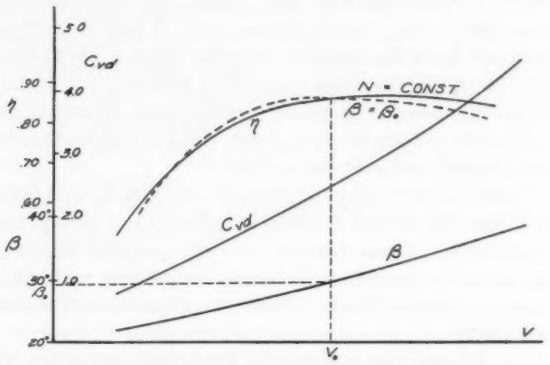

FIG. 12. Characteristics of prototype constant speed propeller and its approximating fixed pitch propeller.

of values of C_P, J, η, and C_T are read off corresponding to this β_0, and C_{Vd} is computed. The value of V for each set of values of the propeller characteristics is determined from the C_{Vd} vs. V curve of Fig. 12, which ensures that the fixed-pitch propeller will always have the same thrust coefficient as the prototype constant speed propeller. The fixed-pitch values of η may now be plotted as shown by the dotted curve of Fig. 12, the differences between it and the constant-speed η curve giving an indication of the differences in slipstream rotation between the two propellers The model values of motor r.p.m. and power are calculated from

$$\left.\begin{aligned} N_m &= \frac{1740}{Jd_m}\sqrt{q/\sigma_m} \\ &\quad (N_m = \text{r.p.m.}, d_m = \text{ft.}, q = \text{lb./ft.}^2 \\ P_m &= C_P \sigma_m N_m^3 d_m^5/5 \times 10^{10} \end{aligned}\right\} \tag{10}$$

where J and C_P correspond to the fixed propeller blade angle β_0. The model operating chart based on these quantities again has the form of Fig. 11.

C. *Actual Operating Procedure*

As has already been mentioned it is desirable in the interests of the highest possible accuracy, to carry out the tests at the largest dynamic pressure which is compatible with the motor and tip speed limitations. The determination of this q is accordingly the first step following the construction of the operating chart. In some cases it is found desirable to use different values of q for different ranges of C_L but the far simpler procedure of employing a single q for the entire investigation is often satisfactory. The following remarks are based on the assumption that this simplification has been adopted, since no real loss in generality accompanies this assumption.

The next step is the model propeller blade setting.

In general the model propeller will not correspond exactly to the propeller chart which has been used in constructing the operating diagram. Hence if the blade setting β_0 is employed the horsepower-r.p.m. relation resulting will not be that of the operating chart. Experience has shown that the most satisfactory procedure in this connection corresponds to the assumption that as a first approximation the characteristics of the model propeller correspond to the basic propeller chart, Fig. 10c, but with the values of β altered in some unknown manner. Accordingly the values of N_m and P_m corresponding to the standard V_0 (and the chosen q) are determined from the operating diagram and the blade angle is adjusted by trial and error until this pair of values is attained.

After the blade angle has been set the first power-on run will give an experimental propeller load curve which may be plotted on the motor calibration chart, Fig. 10b, and on which all subsequent experimental points, with the same propeller blade angle, will be found to lie. This propeller load curve can then be combined with the operating chart to furnish a single curve of power input, P_{m_i} vs. C_L. A curve of motor r.p.m. vs. C_L may also be included on the same diagram. The motor power input can then be set from this figure for all of the remaining tests of the investigation, and a continuous check kept on the r.p.m.

Through the use of the procedure outlined above it has proven possible in a single investigation to study the effect of power on a great number of model configurations, including various nacelles, flap deflections, control surface settings, tail locations, etc., without greatly exceeding the time and expense required for a comparable routine wind-tunnel test on a model without propellers.

Although the investigation of propulsive efficiency was not considered to be one of the primary aims in the development of the apparatus and procedure discussed in this paper, the data for such investigations are obtained incidentally to the other results. It has been a matter of considerable surprise and satisfaction to find that with care propulsive efficiency values can be obtained which, in their scatter and reproducibility, indicate errors of the order of only two or three percent. Furthermore in cases where the model propellers correspond accurately to the propellers employed in obtaining the standard N.A.C.A. propeller charts the agreement between the chart efficiencies and those from the model tests is often of the same order.

IV. Suggested Formulas for a Preliminary Estimate of the Effect of Power on Static Longitudinal Stability

The desirability of some sort of theoretical treatment of the effects of power has already been mentioned and the difficulties of any exact analysis have been indicated. A study of the extensive literature dealing with the aerodynamic characteristic perhaps most importantly affected by power, namely pitching moments, reveals the fact that a large number of workers have considered this problem but none has given anything resembling a complete treatment of it.[3–6] The author has been emboldened to enter here "where angels fear to tread" by the following consideration: If, as has already begun to be the case, power-on tests come to be included in many routine wind-tunnel tests, some sort of systematic framework in terms of which the results may be viewed becomes essential if the mass of data which will then be obtained is to have any usefulness in increasing our general understanding of the phenomena involved. The analytical framework which is here suggested is based on the assumption that each of the component effects of power considered (with the possible exception of one factor which does not affect the final results) may be expressed as a power series in C_L having the form

$$A_1 + A_2 C_L + A_3 C_L^2 + \ldots\ldots$$

where the coefficients A_1, A_2, ... are functions of the thrust coefficient, T_c. It is further assumed that for a first approximation only the first two coefficients A_1 and A_2 need be considered, all the others being neglected. These assumptions were suggested by the fact that certain existing and very crude proposals which have been made relative to various individual power-on effects could be expressed in the above form, and also by the belief that any more complex form for the representation of power effects would lead to such complications in the general framework that the latter would lose all usefulness. The inherent complexities in the problem are indicated by the unpleasantly complicated nature of the formulas which result even with this extreme simplification in the basic assumptions. After completing the analysis we shall return to a brief discussion of the application of the final formulas to the analysis of wind-tunnel tests and to preliminary design problems.

We are here primarily concerned with static longitudinal stability and control which may be expressed either by giving $C_M = C_M(C_L)$ or $C_M = C_M(\alpha)$. At and above the stall the second is without doubt the more significant and convenient. However below the stall the first has great advantages of which the following are the most important:

(a) In actual steady flight the fundamental variable determining the state of operation of an airplane is the flight speed V, which immediately specifies C_L through the equilibrium condition. α cannot be directly determined in flight without special instruments. The preassigned power operating conditions can therefore be given in the form $T_c(C_L)$.

(b) The downwash characteristics which are of fundamental importance to stability questions depend theoretically on lift coefficient and not on angle of attack.

(c) In analysing pitching moment curves the effect of horizontal C.G. variations is much more easily determined from C_M vs. C_L curves than from C_M vs. α curves.[9]

In view of these factors we shall throughout consider C_L as the fundamental independent variable and α as a dependent variable. The chief object of our investigation is therefore to find expressions for $C_M = C_M(C_L)$. It is incidentally necessary to find $\alpha = \alpha(C_L)$ as well. Four model configurations ("Model" will denote either the actual airplane or its wind-tunnel model) must be considered:

(a) Model with no tail, no power, denoted by $(\ )_w$;
(b) " " " ", with " , " " $(\ )_w^P$;
(c) " " tail, no " , " " $(\ )$;
(d) " " ", with " , " " $(\ )^P$.

Only cases (c) and (d) are of importance in actual flight but (a) and (b) may be tested in the wind tunnel and furnish much valuable information. The final material with which we are concerned, in terms of the basic notation given in Fig. 13, may be indicated graphically by the schematic diagrams of Fig. 14.

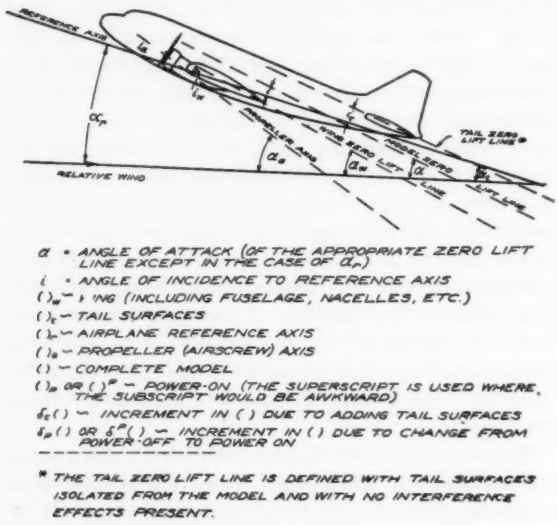
REFERENCE AXIS
RELATIVE WIND
PROPELLER AXIS
WING ZERO LIFT
TAIL ZERO LIFT LINE*
α = ANGLE OF ATTACK (OF THE APPROPRIATE ZERO LIFT LINE EXCEPT IN THE CASE OF α_r)
i = ANGLE OF INCIDENCE TO REFERENCE AXIS
$(\ )_w$ — WING (INCLUDING FUSELAGE, NACELLES, ETC.)
$(\ )_t$ — TAIL SURFACES
$(\ )_r$ — AIRPLANE REFERENCE AXIS
$(\ )_a$ — PROPELLER (AIRSCREW) AXIS
$(\ )$ — COMPLETE MODEL
$(\ )_p$ OR $(\ )^P$ — POWER-ON (THE SUPERSCRIPT IS USED WHERE THE SUBSCRIPT WOULD BE AWKWARD)
$\delta_t(\ )$ — INCREMENT IN $(\ )$ DUE TO ADDING TAIL SURFACES
$\delta_p(\ )$ OR $\delta^P(\ )$ — INCREMENT IN $(\ )$ DUE TO CHANGE FROM POWER-OFF TO POWER ON
* THE TAIL ZERO LIFT LINE IS DEFINED WITH TAIL SURFACES ISOLATED FROM THE MODEL AND WITH NO INTERFERENCE EFFECTS PRESENT.

FIG. 13. Basic notation used in the analysis.

Each of the curves $(\ )^P$ for power-on corresponds to a specific relation between T_c and C_L which is assumed to be given. If this relation is changed a different set of power curves will result.* It is assumed that the curves $\alpha_w(C_L)$ and $C_{M_w}(C_{L_w})$ are known either from numerical estimation or from wind-tunnel tests. Normal wind-tunnel tests without propellers, giving $\alpha(C_L)$ and $C_M(C_L)$, will also often be available. In the following analysis we shall, however, not assume that this is the case.

* The final curves for $T_c(C_L)$ are actually constructed from families of curves like those of Fig. 14, which correspond to T_c = constant.

Two assumptions which are almost universally made in connection with the pitching moment due to the tail, and which we shall adopt, are

(a) The force on the tail normal to the airplane reference axis is numerically equal to the lift on the tail.
(b) The tail moment caused by the component of tail force parallel to the reference axis is negligible.

A further assumption which we make is

(c) In the region of normal flight considered the curves of α vs. C_L (Fig. 14b) are all straight lines.

For power-on these curves are required to correspond to T_c = constant, and the assumption of linearity rests upon the basic assumption with regard to power effects which was mentioned near the beginning of this section.

The analysis corresponds to the usual case of an airplane with one or more tractor propellers in front of a wing and with tail surfaces well downstream from the wing. The influence of deflected flaps is not specifically considered but the modifications to the analysis which would be required to take this effect into account should not be serious. Items of notation not included in

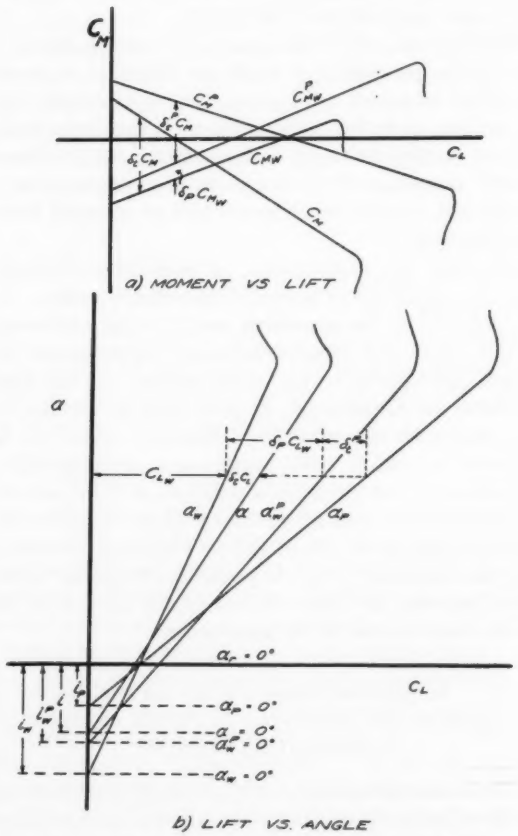

FIG. 14. Typical moment and lift coefficient characteristics for constant T_c.

Fig. 13 are described in the text and collected in the summary at the end of the paper. The use of the subscript w to indicate the complete model without tail surfaces is justified by the fact that the presence of fuselage, nacelles, etc., in general contributes only minor corrections to the lift, angle of attack, and moment arising from the wing itself.

A. Power-Off Analysis

The power-on analysis requires the introduction of so many parameters that it can readily be comprehended and utilized only if it is considered as an extension or generalization of the simpler power-off case. We therefore begin by investigating $C_M(C_L)$ and $\alpha(C_L)$ assuming $C_{M_w}(C_{L_w})$ and $\alpha_w(C_{L_w})$ as given.

In accordance with the notation adopted we have

$$L = L_w + \delta_t L$$
$$M = M_w + \delta_t M$$

where, letting l be the tail length, $\delta_t M = -l\delta_t L$. Expressing these quantities in coefficient form, and defining C_{L_t} in terms of the tail area, S_t, and the average dynamic pressure at the tail, q_t, we have

$$\left.\begin{aligned} C_L &= C_{L_w} + (q_t/q)(S_t/S)C_{L_t} \\ C_M &= C_{M_w} + \delta_t C_M = C_{M_w} - (q_t/q)(l/c)(S_t/S)C_{L_t} \end{aligned}\right\} \quad (11)$$

The lift coefficient which the tail surfaces would furnish if they were tested alone in a uniform wind stream with dynamic pressure q_t is given by $a_t\alpha_t'$ where a_t is the slope of the lift curve of the tail surface and α_t' is its angle of attack. On the airplane the angle of attack of the tail surface is reduced by ϵ, the average downwash over the tail produced by the wings. Hence, referring to Fig. 13, $\alpha_t' = \alpha_t - \epsilon = \alpha - \epsilon + i_t - i$. Furthermore on the airplane the wings (including fuselage, nacelles, etc.) have disturbing interference effects on the tail, so that the lift developed may be different from that which would occur if the tail were tested alone. We introduce a multiplicative correction factor ζ_t to take account of this difference. It is also found desirable to replace a_t by a_{ti} = ideal slope of the tail lift curve for elliptical distribution, and to include the ratio a_t/a_{ti} in the correction factor ζ_t. Then

$$C_{L_t} = \zeta_t a_{ti}(\alpha - \epsilon + i_t - i) \quad (12)$$

It appears most convenient to express the downwash ϵ in terms of the theoretical downwash ϵ_0 which would exist at the center of pressure of the wing if it had elliptical lift distribution and were furnishing the actual C_{L_w}. We therefore write

$$\epsilon = m\epsilon_0;\ \epsilon_0 = C_{L_w}/\pi A \quad (13)$$

where A is the aspect ratio of the wing. The parameter m will be discussed later after the formal analysis has been completed (section IV-C). In view of our assumption of linear lift curves it follows that $dC_L/d\alpha$ for the complete model is a constant $= a(say)$, so that $\alpha = C_L/a$ and (12) becomes

$$C_{L_t} = \zeta_t a_{ti}(C_L/a - mC_{L_w}/\pi A + i_t - i) \quad (14)$$

We eliminate C_{L_w} by using the first equation of (11) and obtain

$$C_{L_t} = \frac{\zeta_t a_{ti}}{1 - \zeta_t(q_t/q)(S_t/S)(m/\pi A)a_{ti}}\left(\frac{1 - ma/\pi A}{a}C_L + i_t - i\right)$$

It is convenient to write $a = ra_t = ra_0/(1 + a_0/\pi A)$. Then, since $a_{ti} = a_0/(1 + a_0/\pi A_t)$, the above equation may be reduced to

$$C_{L_t} = \frac{\zeta_t}{1 - \zeta_t(q_t/q)(S_t/S)(m/\pi A)a_{ti}}\left[\frac{1 - (rm - 1)a_0/\pi A}{r(1 + a_0/\pi A_t)}C_L + a_{ti}(i_t - i)\right]$$

The quantity $\zeta_t q_t/q$ is usually called the tail efficiency factor and written η_t. The small correction factor $\eta_t(S_t/S)$-$(m/\pi A)a_{ti}$ we denote by τ. Introducing these symbols we have finally

$$C_{L_t} = \frac{\zeta_t}{1 - \tau}\left[\frac{1 - (rm - 1)a_0/\pi A}{r(1 + a_0/\pi A_t)}C_L + a_{ti}(i_t - i)\right] \quad (15)$$

and from Eq. (11)*

$$\delta_t C_M = \frac{-\eta_t l S_t/cS}{1-\tau}\left[\frac{1-(rm-1)a_0/\pi A}{r(1+a_0/\pi A_t)}\,C_L + a_{ti}\,(i_t - i)\right] \tag{16}$$

In this expression η_t must be determined empirically or estimated from past experience, m is determined by the geometry of the airplane as described later and r and i are determined from the lift *vs.* angle curves $\alpha(C_L)$ and $\alpha_w(C_{L_w})$. Of these $\alpha_w(C_{L_w})$ is given, in the range of interest, by $C_{L_w} = a_w\alpha_w = a_w(\alpha_r + i_w)$ where a_w, and i_w are assumed to be known. In order to obtain the lift curve for the complete model the parameters a and i in $C_L = a\alpha = a(\alpha_r + i)$ must be determined. From Eqs. (11), (12), and (13),

$$C_L = C_{L_w} + \eta_t(S_t/S)a_{ti}[\alpha - (mC_{L_w}/\pi A) + i_t - i] \tag{17}$$

Now differentiating with respect to α and noting that† $dC_L/d\alpha = a$, $dC_{L_w}/d\alpha = dC_{L_w}/d\alpha_w = a_w$,

$$a = a_w + \eta_t(S_t/S/)a_{ti}\,(1 - ma_w/\pi A)$$

Dividing by a_i and introducing $r_w = a_w/a_i$, corresponding to the lift slope ratio r already employed, a little calculation gives

$$r = r_w + \eta_t(S_t/S)\,\frac{1-(r_w m-1)a_0/\pi A}{1+a_0/\pi A_t} \tag{18}$$

To obtain i we consider $C_L = 0$, then $\alpha = 0$ and $C_{L_w} = a_w(i_w - i) = r_w a_i(i_w - i)$ (cf. Fig. 14b). Eq. (17) now becomes

$$0 = r_w a_i(i_w - i)\,(1-\tau) + \eta_t(S_t/S)a_{ti}(i_t - i)$$

Solving for i we obtain

$$i = \frac{i_w + i_t\{\eta_t(S_t/S)(a_{ti}/a_i)\}/\{r_w(1-\tau)\}}{1+\{\eta_t(S_t/S)(a_{ti}/a_i)\}/\{r_w(1-\tau)\}} \tag{19}$$

The lift curve for the complete airplane is now given by

$$C_L = ra_i(\alpha_r + i) \tag{20}$$

where r and i are determined from Eqs. (18) and (19).

One further step is necessary to complete the power-off analysis. We assume $C_{M_w}(C_{L_w})$ is given, but to obtain the complete $C_M(C_L)$ curve we must have $C_{M_w}(C_L)$. If C_{M_w} is given as an analytical function of C_{L_w} it may be transformed to a function of C_L using Eq. (17). It will usually be more convenient, however, to plot the curves of C_{L_w} and C_L as functions of α_r and read off the values of C_{L_w} corresponding to given values of C_L. This is particularly true when, as is often the case, $C_{Mw}(C_{L_w})$ is not represented by a straight line even below the stall.

The analysis given above is considerably more refined than has usually been used in the past for power-off stability estimates. As suggested by the footnote following Eq. (16) the latter have usually been based on simplifying assumptions such as the equality of C_{L_w} and C_L. When the effects of power are considered the influence of these and other analogous simplifications is no longer negligible. The detailed analysis above has therefore been presented in part to serve as a guide to the more complex power-on analysis.

B. Power-On Analysis

With power applied to the propellers we have in place of Eq. (11):

$$\left.\begin{aligned} C_L &= C_{L_w} + \delta_P C_{L_w} + (q_t^P/q)(S_t/S)C_{L_t} \\ C_M^P &= C_{M_w} + \delta_P C_{M_w} + \delta_t^P C_M = C_{M_w} + \delta_P C_{M_w} - (q_t^P/q)(lS_t/cS)C_{L_t}^P \end{aligned}\right\} \tag{21}$$

---

* An approximate form of Eq. (16) has been widely used in practice. This is obtained by assuming $r = 1$, $m = 2$, and putting $\tau = 0$. The resulting expression is

$$\delta_t C_M = -\eta_t(lS_t/cS)\left[\frac{1-a_0/\pi A}{1+a_0/\pi A_t}\,C_L + \frac{a_0}{1+a_0/\pi A_t}\,(i_t - i)\right]$$

† In carrying out this differentiation we are for the moment abandoning our conception of C_L as the independent variable, and considering α as having this character. From this viewpoint it is clear that $dC_{L_w}/d\alpha = dC_{L_w}/d\alpha_w$ since, at a given attitude, the lift on the wing is assumed to be unaffected by the presence of the tail.

Here, as is indicated, the increments $\delta_P C_{L_w}$ and $\delta_P C_{M_w}$ are those due to power with tail surfaces removed. The parameter defining power is taken as the thrust coefficient T_c and the analysis will in general be carried out for constant values of T_c. The various terms will be considered individually, their dependence on power being indicated symbolically in order to facilitate the analysis. Suggested expressions for the symbols so introduced will be presented in section IV-C below.

$\delta_P C_{L_w}$

Here two effects must be considered: the lift due to the inclined propeller itself, and the lift due to the interaction of the propeller slipstream with the wing. In accordance with our basic assumption as to the dependence of individual power-on effects on C_L and T_c these two effects may be combined into an expression of the form

$$\delta_P C_{L_w} = f_L C_L + g_L \tag{22}$$

where f_L and g_L are functions of T_c which for constant T_c are independent of C_L. Suggested expressions for them are given later.

$\delta_P C_{M_w}$

Here the same two effects as contributed to $\delta_P C_{L_w}$ must be considered. In general it may not be possible to give an expression of the form of (22) for $\delta_P C_{M_w}$ since this term may depend on the power-off relation $C_{M_w}(C_{L_w})$ which is often not given in analytical form. For the purpose of the present analysis we therefore write this component of the moment simply as $\delta_P C_{M_w}$, returning in the next section to give a suggested expression for it.

q_t^P/q

We obtain an expression for this ratio using the following assumptions:

(a) The slipstream velocity is determined from the simple Froude momentum theory for a propeller without interference effects.

(b) The tail is supposed to be far enough downstream so that the slipstream velocity theoretically developed at infinity has already been attained at the tail surfaces.

We denote the inflow velocity at the propeller by μ (instead of the usual notation of a) so that the slipstream velocity at the tail is given, in view of b), by $V_s = V(1 + 2\mu)$. An elementary calculation then gives for the dynamic pressure in the slipstream at the tail: $q_s = q(1 + 8T_c/\pi)$. It is now assumed that a fraction Q of the tail surface lies in the slipstream while the remainder is acted upon by the undisturbed dynamic pressure q. The dynamic pressure averaged over the horizontal tail surface is denoted by q_t which is seen to be given by*

$$(q_t/q) = 1 + 8QT_c/\pi \tag{23}$$

Following Smelt and Davies it is recommended that Q be taken as the fraction of the tail surface area lying between two concentric cylinders around each propeller axis and having diameters of 0.2 and 0.8 the propeller diameter, respectively.

ϵ_P = downwash at the tail with power-on

Before investigating $C_{L_t}^P$ it is necessary to consider ϵ_P. This downwash term is almost certainly the most complex factor entering into the problem and has never as yet received any satisfactory theoretical treatment. The expression suggested here is based on British experiments as indicated in the next section, and should suffice to represent approximately the major effects of power-on downwash. We write

$$\epsilon_P = (mC_{L_w}/\pi A) + f_D \alpha_P + g_D \tag{24}$$

where the first term is the power-off downwash and f_D and g_D are functions of T_c similar in character to the lift terms f_L and g_L.

$C_{L_t}^P$ and $\delta_t^P C_M$

For the power-on case we have, corresponding to Eq. (12),

$$C_{L_t}^P = \zeta_t^P a_{tt}(\alpha_P - \epsilon_P + i_t - i_P) \tag{25}$$

where ζ_t^P is a power-on correction factor analogous to the power-off ζ_t.

Using Eq. (24) and introducing the power-on lift curve slope $a_P = C_L/\alpha_P$, Eq. (25) becomes

$$C_{L_t}^P = \zeta_t^P a_{tt}[(C_L(1 - f_D)/a_P) - (mC_{L_w}/\pi A) + i_t - i_P - g_D]$$

We eliminate C_{L_w} using the first equation of (21) which, in view of Eq. (22), gives

* This expression is given by Smelt and Davies[10] and by Helmbold.[6]

$$C_{L_w} = (1 - f_L)C_L - (q_t^P/q)(S_t/S)C^P{}_{L_t} - g_L \tag{26}$$

Following exactly the procedure which led to Eq. (15),

$$C_{L_t}{}^P = \frac{\zeta_t^P}{1 - \tau_P}\left[\frac{1 - (rr_Pm - 1)a_0/\pi A - f_D(1 + a_0/\pi A) + f_L rr_P m a_0/\pi A}{rr_P(1 + a_0/\pi A_t)} C_L + a_{tt}(i_t - i_P + g_L m/\pi A - g_D)\right] \tag{27}$$

where

$\tau_P = \eta_t^P(S_t/S)(m/\pi A)a_{tt}$

$\eta_t^P = \zeta_t^P q_t^P/q$ = power-on tail efficiency factor

$r_P = a_P/a = \dfrac{\text{lift curve slope of complete airplane, power-on}}{\text{lift curve slope of complete airplane, power-off}}$

From the second equation of (21) and (27) we immediately obtain

$$\delta_t^P C_M = \frac{-\eta_t^P l S_t/cS}{1 - \tau_P}\left[\frac{1 - (rr_Pm - 1)a_0/\pi A - f_D(1 + a_0/\pi A) + f_L rr_P m a_0/\pi A}{rr_P(1 + a_0/\pi A_t)} C_L + a_{tt}(i_t - i_P + g_L m/\pi A - g_D)\right] \tag{28}$$

In these two expressions three quantities remain to be discussed in addition to the parameters considered in the next section. These are η_t^P, r_P and i_P.

η_t^P differs from η_t both in the dynamic pressure ratio and in the multiplicative correction or averaging ζ factor. For the former we have a theoretical estimate in Eq. (23) which it is desirable to exhibit explicitly. Accordingly we write

$$\eta_t^P = A_P(1 + 8QT_c/\pi)\eta_t \tag{29}$$

where A_P may be called a "power-on averaging factor" and must be determined empirically. In this way the major portion of the variation of η_t^P with power is taken into account and only secondary variations should appear in A_P.

r_P and i_P are determined by procedures identical with those leading to Eqs. (18) and (19). The final expressions are:

$$r_P = \frac{r_w}{r} + (r_P f_L) + \eta_t^P \frac{S_t}{S}\frac{1 - (r_w m - 1)a_0/\pi A - f_D a_0/\pi A}{r(1 + a_0/\pi A_t)} \tag{30}$$

$$i_P = \frac{i_w + (i_t - f_D i_w + g_{L_1})\{\eta_t^P(S_t/S)(a_{tt}/a_t)\}/\{r_w(1 - \tau_P)\}}{1 + (1 - f_D - g_{L_2})\{\eta_t^P(S_t/S)(a_{tt}/a_t)\}/\{r_w(1 - \tau_P)\}} \tag{31}$$

where, as appears in the next section,

$$g_L = \eta_t^P(S_t/S)a_{tt}(g_{L_1} + i_P g_{L_2});\ g_D = f_D(i_w - i_P)$$

and f_D, g_{L_1}, g_{L_2} are independent of i_P. The expression $(r_P f_L)$ is independent of r_P.

The power-on lift curve for the complete airplane is now given by

$$C_L = r_P r a_t(\alpha_r^P + i_P)$$

C. *Tentative Expressions for the As Yet Undefined Parameters*

The expressions suggested in this section are in several instances extremely tentative. Some are purely empirical in nature and are based on very meager experimental data. One of the chief aims of the present analysis has been the presenting of expressions for power-on static stability which would permit the determination of power-on correction factors from routine power-on wind-tunnel tests. The particular forms for the factors given below are therefore to be considered only as very rough approximations which should be modified and improved as additional experimental data become available. For example the effect of slipstream rotation, which is not here considered, is known to be of considerable importance and should be studied as soon as sufficient information has been obtained.

m

This power-off downwash factor has been the subject of many investigations both theoretical and experimental. Charts giving m in terms of the model geometry and wing angle of attack have been developed as a result of theoretical analysis both in Germany[3] and in the United States,[11] and experiments on wing-tail combinations have furnished satisfactory agreement with the theory. According to these theoretical charts the value of m for a particular airplane varies somewhat

with angle of attack. In determining an m for use in the formulas of this paper a mean value of m must be taken when these charts are used. It is also possible to determine both m and η_t from wind-tunnel tests in which measurements are made with several stabilizer angles and with tail surfaces removed. A large number of such investigations at the GALCIT has indicated that, at least for conventional landplanes, m may practically always be taken as constant and that the numerical value 2 is surprisingly accurate. It is therefore suggested that the value $m = 2$ be chosen for preliminary estimates when neither the downwash charts nor adequate power-off wind-tunnel tests are available.

η_t, r_w

These two power-off parameters are essentially empirical in nature. For a particular airplane they can be determined from wind-tunnel tests of the character mentioned just above, or, if such tests are not available for the airplane in question, they may be estimated on the basis of previous experience obtained from tests on comparable models. Root[15] has collected a large amount of empirical information on η_t (called η_H in his paper). Although Root's definition of tail efficiency factor is slightly different from that used here, the influence of this difference on the resulting numerical values is negligible. Accordingly Root's values may be employed directly if specific data on η_t are not at hand. For r_w values lying between 0.98 and 1.02 have been found as a result of tests at the GALCIT on a large number of modern models. An average value of 1.00 is recommended.

$\delta_P C_{L_w}$

The first contribution to $\delta_P C_{L_w}$ is the lift increment due to the propeller itself. The component of the thrust acting in the lift direction gives a lift increment.

$$C_L = 2\nu(d^2/S)T_c\alpha_a = 2\nu(d^2/S)T_c(\alpha_P + i_a - i_P)$$

where ν is the number of propellers and d is the propeller diameter. There is also a normal component of force on a propeller inclined in pitch, but a numerical investigation has shown that the lift increment due to this phenomenon is usually negligible, although the pitching moment produced by it may be important and is in fact considered below.

We must now consider the lift due to the interaction of propeller slipstream and wing. Smelt and Davies[10] have investigated this question theoretically and experimentally, and have given a formula which has been quite satisfactorily vertified by their own and other experiments. The expression suggested here is a slightly modified form of that given by Smelt and Davies:

$$\delta C_L = \nu(d^2/S)(c_a/c)s\sqrt{(1+\mu)/(1+s)} \times (\lambda C_{l_0} - 3.42\theta)$$

where

c_a = wing chord behind center line of airscrew (propeller),

μ = inflow velocity at the propeller disk = $\frac{1}{2}[(1 + 8T_c/\pi)^{1/2} - 1]$,

s = inflow velocity at the wing C.P. = $\mu[1 + x \div (d^2/4 + x^2)^{1/2}]$,

x = distance of wing C.P. downstream from propeller disk,

λ = empirical constant between 1 and 2, depending on the aspect ratio of the wing portions covered by slipstream. It is given by Smelt and Davies in the form of a curve which is reproduced in Fig. 15,

C_{l_0} = lift coefficient of the airfoil section behind propeller center line with power-off,

θ = downwash at the wing C.P. behind the propeller center line, due to propeller = $(1 - 0.07\,x/d) \times [\mu/(1+\mu)](\alpha_P + i_a - i_P)$.

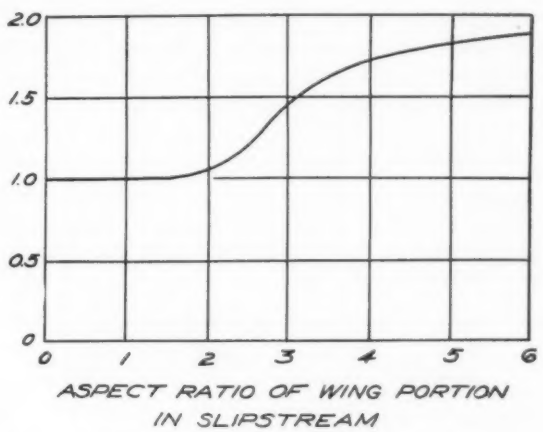

FIG. 15. Empirical factor for wing lift due to slipstream.

(The last expression is not identical with that of Smelt and Davies but has been found to give results indistinguishable from theirs for normal airplanes. The so-called "Boss Correction" of Smelt and Davies has been omitted since it is found to be negligible for modern airplane designs.)

It is necessary to express C_{l_0} in terms of overall wing characteristics which is done by assuming the slope of the lift curve for the wing section in question to be the same as the slope of the lift curve for the complete wing. Writing t = incidence of the zero lift line of the airfoil section behind the propeller center line to the wing zero lift line (local wing twist), we have then

$$C_{l_0} = r_w a_i(\alpha_P + t + i_w - i_P)$$

Collecting terms and remembering Eq. (22), $\delta_P C_{L_w} = f_L C_L + g_L$, we obtain

$$
\left.
\begin{aligned}
r_P f_L &= \frac{\nu(d^2/S)}{r a_i}\,[2T_c + K_1(\lambda r_w a_i - K_2)] \\
g_{L_1} &= \frac{\nu(d^2/S)[i_a(2T_c - K_1K_2) + (i_w + t)K_1\lambda r_w a_i}{(\eta_i{}^P a_{ii} S_t/S)} \\
g_{L_2} &= \frac{\nu(d^2/S)[-2T_c + K_1(K_2 - \lambda r_w a_i)]}{(\eta_i{}^P a_{ii} S_t/S)} \\
g_L &= (\eta_i{}^P a_{ii} S_t/S)(g_{L_1} + i_P g_{L_2})
\end{aligned}
\right\} \quad (32)
$$

where

$$
\left.
\begin{aligned}
K_1 &= (c_a/c)s\,\sqrt{(1+\mu)/(1+s)} \\
K_2 &= 3.42(1 - 0.07x/d)\mu/(1+\mu)
\end{aligned}
\right.
$$

f_D and g_D

For the downwash at the tail with power on a relatively simple empirical expression was suggested by Bryant, Williams, and Brown,[12] which gave very satisfactory agreement with experiment on several airplane models of very different types. This is apparently the only formula which has been proposed which is reasonably simple and has furnished such agreement. In the terminology of our Eq. (24), $\epsilon_P = mC_{L_w}/\pi A + f_D\alpha_P + g_D$, the British expression corresponds to

$$
\left.
\begin{aligned}
f_D &= B_P QR(R-1)/[1 + Q(R-1)] \\
R &= 1 + 8T_c/\pi \\
Q &= \text{fraction of tail in slipstream as defined following Eq. (23).} \\
B_P &= \text{empirical coefficient for which the value 0.3 is suggested for modern, multi-engined monoplanes.*}
\end{aligned}
\right\} \quad (33)
$$

It follows from Eq. (24) that

$$g_D = (\epsilon_P - f_D\alpha_P)_{(C_{L_w}=0)}$$

In evaluating g_D we make use of the experimental fact found by Stüper[8] and other investigators that inclination of a tractor propeller axis to the wing chord behind it has no appreciable effect on the resulting downwash at the tail. We accordingly calculate g_D for the specially simple case in which the propeller axis is parallel to the wing zero lift line. Then for $C_{L_w} = 0$ the lift on the propeller is also zero so that $\epsilon_P = 0$. For this case then

$$g_D = -f_D(\alpha_P)_{C_{L_w}=0}$$

But from Fig. 14b $(\alpha_P)_{C_{L_w}=0} = i_P - i_w$. Hence

$$g_D = f_D(i_w - i_P) \quad (34)$$

* The British authors suggest $B_P = 0.155$ as a result of measurements on single-engined braced biplane models. The value suggested here is based on rather meager data which should be supplemented by additional experimental material.

We assume that this expression is valid for any normal propeller incidence and is not restricted to the special value of propeller incidence used in deriving it. In view of the experimental observation mentioned above and the fact that normal propeller incidences are usually very small this assumption would appear to be justified.

$\delta_P C_{M_w}$

This term is analogous to $\delta_P C_{L_w}$ in that direct propeller effects and propeller-wing interference must both be considered. It is convenient to divide the moment due to the propeller alone into three parts. With the notation indicated on Fig. 16 we have:

$$\delta M = -Tz_a + N_a x_a + M_a$$

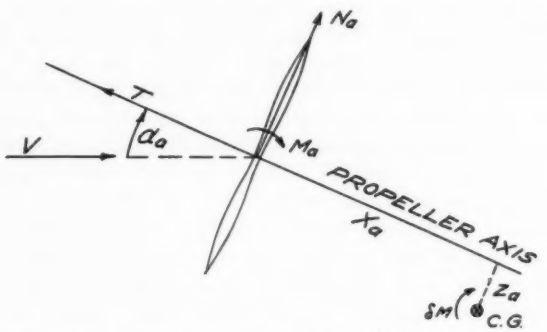

FIG. 16. Forces and moments produced by an inclined propeller.

N_a is the term which we neglected in calculating the lift due to the propeller. However, because of its large lever arm, it may have an important effect on the moment. Glauert[4,13] has investigated theoretically the problem of the inclined propeller and finds that, for small values of α_a, $M_a = 0$ while N_a is given by

$$N_a = [\rho V^2 d^2 f C_P/2\pi J]\,[1 - {}^1/_2(J/C_P)dC_P/dJ]\,\alpha_a$$

where f is a numerical factor depending on the torque grading, and J and C_P have their usual meanings. In his earlier analysis Glauert gives a numerical value for f while in his later work this is replaced by a function of J. Glauert's expression has been compared with experimental data given by Lesley and some of his colleagues[14] and excellent agreement obtained if the earlier numerical value $f = 2.3$ is used. We accordingly adopt this expression for f.

Turning now to the moment produced by the interference effects of slipstream on wings it has been found (as a result of fairly limited experience) that this moment is quite small for conventional airplanes and appears to be chiefly affected by local propeller-nacelle interferences rather than by any systematic propeller-wing interaction. For normal airplanes, in which the center of pressure of the wing portion in the slipstream is longitudinally not very distant from the airplane center of gravity, it is accordingly suggested that this

interference effect be neglected. The term $\delta_P C_{M_w}$, then, includes only the direct effect of the propeller and is given by

$$\left.\begin{aligned}\delta_P C_{M_w} = \nu \frac{x_a d^2}{cS}\Bigg[&- 2\frac{z_a}{x_a} T_c + 0.73 \frac{C_P}{J} \times \\ &\left(1 - \frac{1}{2}\frac{J}{C_P}\frac{dC_P}{dJ}\right)\left(\frac{C_L}{r_P r a_i} + i_a - i_P\right)\Bigg] \\ = f_M C_L &+ g_M(say)\end{aligned}\right\} \quad (35)$$

For constant-speed propellers dC_P/dJ corresponds to the fixed-pitch propeller having the same blade angle as the actual propeller. It will be observed that, because of the special assumptions employed, Eq. (35) has the same form as the other individual power effects. This may not be the case in general, but the final analysis is not affected by the form of $\delta_P C_{M_w}$, as has been indicated before.

D. *Use of the Formulas of Part IV*

As has already been mentioned two motives underlay the development of the expressions of this part of the paper. The first was to furnish a framework for the correlation of the results of power-on wind-tunnel work. This framework has been given such a form that, as a result of routine or systematic tests, empirical values can be determined for many of the parameters which appear. Lack of space prevents the inclusion of the transformed formulas which exhibit explicitly the dependence of the various parameters on experimentally determinable characteristics. These, however, are readily deduced from the expressions given in the paper.

The second motive was to give the designer some method of obtaining at least a rough, preliminary estimate of the power-on longitudinal stability characteristics of a new model. Since it may serve to clarify and summarize the preceding analysis a procedure for the carrying out of such an estimate is outlined below.

Assumed as given are:

(a) The airplane's geometrical and other basic design characteristics.

(b) The power operating conditions in the form $C_{Vd}(C_L)$ or $T_c(C_L)$.

(c) The propeller characteristics in the form of a chart corresponding to Fig. 10c.

If no wind-tunnel tests on a model of the airplane are available the initial steps in the procedure are:

(1) Estimate $C_{M_w}(C_{L_w})$ and $C_{L_w} = r_w a_i(\alpha_r + i_w)$ from standard data on the aerodynamic characteristics of the wing, taking into account the modifications expected as a result of the disturbing effect of fuselage, nacelles, etc.

(2) Determine an average value of m from downwash charts or, if these are not available and the model is fairly conventional, assume $m = 2$.

(3) Estimate η_i from past experience with similar models or from published statistical data.[15]

(4) Calculate r and i from Eqs. (18), (19). This permits the plotting of the lift curve for the complete model, power-off, and hence gives $C_{M_w}(C_L)$.

(5) Calculate $\delta_i C_M$ from Eq. (16) and add to $C_{M_w}(C_L)$ to obtain $C_M(C_L)$. The power-off stability and trim characteristics are thus determined.

If conventional power-off wind-tunnel tests are available $C_M(C_L)$ is given. If measurements have been made with several stabilizer settings and with tail surfaces removed, all of the following quantities may be determined from the experimental data: r_w, i_w, $C_{M_w}(C_{L_w})$, m, η_i, r, and i. The estimates involved in steps (1) to (5) need not be made in this case. The further steps now proceed as follows, irrespective of the means employed in obtaining the data used up to this point:

(6) Estimate a value of A_P. If data for such an estimate are not available assume $A_P = 1$.

(7) Fix upon a number of constant values of T_c covering the range of values of interest and compute η_i^P from Eq. (29) and τ_P from the expression following Eq. (27). Then calculate $r_P f_L$, g_{L_1}, and g_{L_2} from Eq. (32). From Eq. (33) determine f_D choosing a value for B_P based on past experience or, if this is lacking, take $B_P = 0.30$. If improved expressions for the above parameters are available, they should of course be employed in place of the tentative expressions suggested here.

(8) Determine r_P from Eq. (30) and i_P from Eq. (31). This permits the plotting of the power-on lift curve

$$C_L = r_P r a_i(\alpha_r^P + i_P)$$

(9) Having i_P determine g_D from Eq. (34).

(10) Calculate $\delta_P C_{M_w}$ from Eq. (35) and $\delta_i^P C_M$ from Eq. (28).

(11) Plot $C_M^P(C_L)$ from Eq. (21) for each value of T_c considered.

(12) From the given function $T_c(C_L)$ and the family of $C_M^P(C_L)$ curves determine the final $C_M^P(C_L)$ curve corresponding to the actual power conditions of flight.

Fig. 17 gives the results of a calculation for a particular airplane following the procedure outlined above. Experimental data are also given from wind-tunnel tests. The agreement, while not perfect, may be considered as satisfactory in view of the present tentative state of the "theory," and the fact that the suggested average values A_P and B_P (1 and 0.3, respectively) and of Q were used without any attempt at modification for the purpose of improving the agreement with experiment for this particular example. Additional tests should

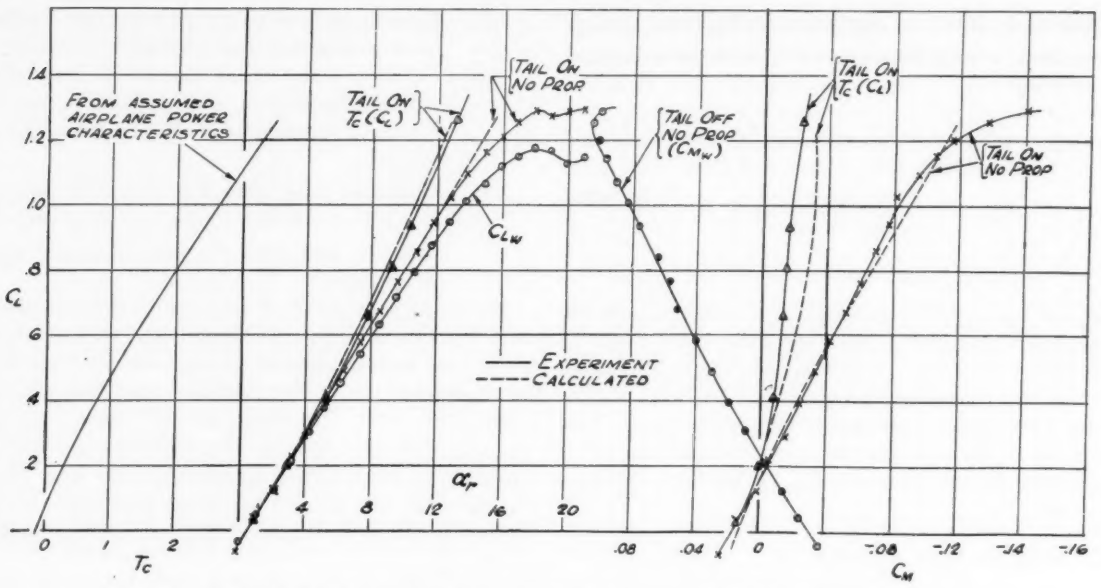

FIG. 17. Calculated and experimental results for a bi-motored cantilever monoplane.

furnish a basis upon which improved values of these quantities can be determined and closer agreement between calculated and observed moment characteristics obtained. The downwash parameter f_D should, in particular, be the subject of such further investigation.

CONCLUSION

The two previous Wright Brothers Lecturers remarked that their lectures ended "on a note of interrogation." It is, if anything, more true of the present lecture than of theirs that the material presented represents only a fraction of that which will be required for a thorough understanding of its subject. I have been emboldened to discuss a field in which so many unanswered questions still remain by my belief that it corresponds to one of the most important aerodynamic problems in contemporary airplane design, and by the clear indications that it will in the near future be the subject of intensive and widespread investigation. The lecture will have served its purpose if it has any influence in stimulating and aiding the efficiency of such investigations, and especially if it furnishes any assistance in correlating and unifying the results obtained.

SUMMARY OF NOTATION USED IN PART IV

S = wing area,
A = " aspect ratio,
c = mean wing chord,
c_a = wing chord behind airscrew-center line,
S_t = horizontal tail surface area,
A_t = " " " aspect ratio,
l = " " length measured parallel to reference axis,
Q = fraction of S_t assumed to lie in the slipstream,
n = number of propellers,
d = propeller diameter,
x = distance of C.P. of c_a behind propeller disk,
x_a = distance of C.G. behind propeller disk, parallel to propeller axis,
z_a = distance of C.G. below propeller disk, perpendicular to propeller axis,
α = angle of attack,
i = " " incidence relative to reference axis,
t = angle " " of the zero lift line corresponding to c_a relative to the wing zero lift line,
$a = dC_L/d\alpha$ = lift curve slope,
a_0 = 5.7 (radians)$^{-1}$ = infinite aspect ratio lift curve slope,
a_i = ideal lift curve slope corresponding to elliptic lift distribution,
$r_w = a_w/a_i$; $r = a/a_i$; $r_P = a_P/a$.

Subscripts r, w, t, a, P, and superscript P: see definitions given in Fig. 13.

ϵ = downwash due to the wing at the horizontal tail,
ϵ_0 = ideal downwash at the wing corresponding to elliptic lift distribution,
$m = \epsilon/\epsilon_0$ = downwash factor,
V = velocity of flight,
$q = \frac{1}{2}\rho V^2$ = free stream dynamic pressure,
q_t = average dynamic pressure over the horizontal tail surface,
$V(1+\mu)$ = slipstream velocity at the propeller,
$V(1+s)$ = " " " C.P. of c_a,
ζ_t = tail load correction factor,
$\eta_t = \zeta_t q_t/q$ = tail efficiency factor.

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No attempt is here made to furnish any exhaustive or even representative bibliography in view of the remarkably complete summary of the pertinent literature given in reference 3.

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Discussion

THE Third Wright Brothers Lecture, entitled "The Influence of Running Propellers on Airplane Characteristics," was delivered by Dr. Clark B. Millikan, Associate Professor of Aeronautics at the California Institute of Technology and a Fellow and past-president of the Institute, at the Pupin Physics Laboratories, Columbia University, at 3:00 p.m. on December 16, 1939. The lecture is held annually to commemorate the first flights of Wilbur and Orville Wright at Kitty Hawk, North Carolina, on December 17, 1903. It is sponsored by the Institute through the "Vernon Lynch Fund."

Before the lecture a luncheon in honor of Dr. Millikan was held at the Men's Faculty Club, Columbia University. Over a hundred members and guests attended. Captain William J. Tate of Kitty Hawk, North Carolina, gave a short talk on "The Wright Brothers at Kitty Hawk." Captain Tate was privileged to witness the first glider flights and Wilbur and Orville Wright stayed at his home for a time while they were conducting their experiments. As a result of this intimate association, Captain Tate was able to give an interesting account of how the site was selected, how the gliding and flying experiments progressed, and how the famous inventors impressed him by their personal characteristics.

Dr. George W. Lewis, President of the Institute, in his introductory remarks at the lecture reviewed the endowment of the lecture by the late Edmund C. Lynch of New York. In transmitting the $10,000 to establish the "Vernon Lynch Fund," Mr. Lynch wrote:

Dr. Clark B. Millikan

"So strongly am I of the opinion that the Wright Brothers Lecture will bring disclosures of advances which will be of practical benefit to aviation—that the Honors Night plan of commemorating this anniversary is so worthy of the occasion—that I believe the Institute should continue this work....."

Carl Vernon Lynch, in whose memory the fund was established, was graduated at The Johns Hopkins University in 1914 and received his Ph.D. in 1918. He saw war service as a physiologist. He died in 1918 as the result of a motorcycle accident.

Dr. Lewis read a cable from A. H. R. Fedden, President of the Royal Aeronautical Society of Great Britain:

"On behalf of the Council and all members of the Royal Aeronautical Society I send you all good wishes for the reading of the Wright Brothers Lecture this year by your distinguished countryman Dr. Millikan. We all deeply regret that circumstances prevent some of us being present to convey our personal high appreciation of the work of the lecturer and of the close and happy cooperation between the Institute and the Society."

In introducing Dr. Millikan, Dr. Lewis reviewed briefly his many contributions to the aeronautical sciences and presented him with an honorarium of $250 from the Vernon Lynch Fund.

The discussion following the lecture is printed below.

Frank W. Caldwell

Hamilton Standard Propeller Division, United Aircraft Corporation

It is easy to understand that Dr. Millikan's research on this subject has required two years, and one is led to suspect that the results of a good many more years of preparation are reflected in the paper. It would be presumptious to undertake an extemporaneous discussion of the work which has been done. The subject of the paper is such a broad one, however, as to present a challenge to anyone with research leanings.

From the standpoint of one who has the problem of attempting to anticipate the needs of the industry, my thoughts are somewhat biased by the question: What are we going to do about it designwise?

Dr. Millikan has pointed out that the race rotation of the slipstream probably has an important bearing on the problem. It appears that its importance is apt to increase if we continue to think of very high-speed airplanes. The resultant propeller tip speed is apt to remain fixed at its present upper limit by compressibility effects so that the V/Nd will increase at a somewhat faster rate than the airplane speed. We are approaching a régime where race rotation will be the major component of the slipstream.

Seifert has concluded from his experiments at D.V.L. that the use of oppositely rotating propellers where the inboard blades are rotating upward leads to an improvement in longitudinal stability and in yawing and rolling stability due to the relative symmetry of the flow pattern. We don't particularly like this conclusion for the propeller, as we have found that the propellers on the right side of the airplane are more sensitive to stresses caused by combined wing and fuselage interference effects than those on the left. However, stress from this source has not proved sufficiently serious to be in any way prohibitive.

The race rotation losses have become so important for very fast airplanes that it has been proposed that the wings adjacent to the power nacelle might be warped in such a way as to serve as a contra-propeller. It does not appear probable that this expedient would lead to any improvement in stability, and it might even be harmful if opposite rotation for the propellers is used.

The pusher propeller installations will undoubtedly bring an entirely new set of problems, and it seems possible that the use of pushers at high values of V/Nd with blades on the inboard side moving upward might even reverse the power-on effect on stability.

One of the obvious ways of recovering a portion of the race rotation energy is the use of two oppositely rotating propellers on the same shaft. It is not clear that this type of propeller would lead to any improvement in longitudinal stability though the greater symmetry of flow might lead to improvement in yaw and rolling. On the other hand, the diameter of these propellers will be restricted by weight considerations and the slipstream velocity will consequently be higher.

With these coaxial counter-rotating propellers there is an interesting problem as to tractor or pusher location from the point of view of turbulence. We shall have to choose between the propeller and the wings as to spoiling effect of the flow. Since the rear one of the two propellers will in any event be operating in turbulent conditions there may be some justification for the pusher arrangement.

Dr. J. C. Hunsaker

Massachusetts Institute of Technology

The Institute is fortunate to receive, and the Journal to publish, this important analysis of an uncertain element in the prediction of airplane performance. Dr. Millikan has made it very clear that the effect of the slipstream on the balance or equilibrium of the airplane makes it very desirable that wind tunnel model testing correctly represent and evaluate this effect. Fig. 1 of his paper indicates a substantial additional pitching moment due to slipstream, which is larger for larger C_L (or angle of trim) and unfavorable for stability. Fig. 1, however, does not disclose the pitching moment curve for this airplane as a whole, but gives only the increment to C_M due to slipstream. Presumably, the increment to C_M may be great enough to cause the slope of the resultant net pitching moment curve to be unfavorable or unstable in nature. Such an effect is shown on Fig. 2.

I believe this may be the place to register an objection to the common practice of ascribing a so-called "static longitudinal stability" to an airplane merely because the curve of C_M has a slope that indicates a righting moment for a change in angle of pitch from the attitude of trim. Strictly speaking, there can be no such thing as static stability for dynamic flight. For a vessel or an airship, the term, of course, has meaning, but the aerodynamic forces on an airplane are due to its motion. If stability characterizes this motion, the stability must be dynamic.

The common practice that I object to seems to result from the very plausible assumption that the slope of the pitching moment curve, $dC_M/d\alpha$, is the determining parameter in the criterion for longitudinal stability given by the equations of motion. The nature of the initial motion from equilibrium is clearly indicated by the classical theory of Bryan and Bairstow, where equations of motion, for small deviations, lead to a biquadratic of the form:

$$A\lambda^4 + B\lambda^3 + C\lambda^2 + D\lambda + E = 0$$

Here the coefficients must all be positive to insure that an initial deviation from equilibrium attitude will not continue in the same sense. Since A, B, C, D are essentially positive, E becomes the critical coefficient to determine stability. The value of E is made up of two terms:

$$E = \mu C_L \left[-\frac{dC_M}{d\alpha} \times \frac{2C_L}{b} + \frac{dC_L}{d\alpha} M_u \right]$$

If M_u, the rate of change of pitching moment with change of forward speed u, is zero, it follows that E would always be positive when the curve of C_M on α has a negative slope.

For extreme speeds, as in a dive, C_L becomes very small while $dC_L/d\alpha$ remains constant. Consequently, if M_u is not zero, the

first term may become small in comparison with the second and E might be negative.

The assumption that M_u is zero is tacitly made by Dr. Millikan, and I object to this as unnecessary in his case, as he is in possession of the experimental means to measure M_u.

I also must confess some sense of guilt in the matter myself. In 1916 I published the first stability analysis made in this country in which I took pains to point out that, for an airplane in trim, C_M is zero and must remain zero for change of speed. Hence M_u is zero and may be omitted in the evaluation of E. This argument was applied to an airplane operating as a glider. It still is a good argument, but with running propellers the argument does not apply and, consequently, its conclusion is pure assumption.

Dr. Millikan has just shown us tools of experimentation and analysis of great refinement, and I urge him to apply them to determine M_u for some typical airplanes, especially at the high speed attitude. There is a gap in the theory of stability which he could fill in very easily by running his models with appropriate variations of V/Nd.

With all respect, I suggest that Dr. Millikan may be somewhat in the position of the fisherman who tries for a catfish, using refined and delicate tackle that should catch a fine trout.

Donald H. Wood

National Advisory Committee for Aeronautics

I wish to add my thanks to Dr. Millikan for the excellence and timeliness of his lecture. Even assuming much of the material presented was at hand, it was no small task to get it in order in the limited time available.

I am sure we must be impressed by the complexity of the subject. We cannot be content with overcoming the difficulties of designing the propeller to absorb a given power efficiency but must reckon with the effects of slipstream and torque on the airplane. I believe that efforts will continue along all of the three lines of attack suggested by Dr. Millikan, and I agree that to solve the day-to-day problems we must continue to test models of designs as they arrive.

I note that the problem of the basic research is again handed to "large Government laboratories." At present these laboratories, wherein large wind tunnels are available, are largely concerned with development or ad hoc testing in connection with the Service expansion programs, so that the basic research has had to be somewhat curtailed. There are certain factors related to high speeds and to model scale which can only be studied under the proper conditions, however, and the construction and use of larger, higher speed wind tunnels, even for apparently routine testing, is yielding valuable results. In this connection it may be noted that the power required to drive small propellers at high speeds leads to problems which cannot be perfectly handled even with the remarkably small motors now available. We have been using somewhat larger water-cooled motors at Langley Field for a number of years with success, although with some complications due to extra plumbing. I do not think that direct measurement of the torque reaction is entirely out of the question. The mounting of the motor with the gimbal bearings directly on the rotating shaft rather than on the frame has been found to reduce friction variations and often decreases the overall diameter compared with other mountings.

The importance of accurate and easily read revolution indicators cannot be overemphasized. The ordinary tachometer simply has to be read but is not accurate enough. The tachometer described by Dr. Millikan would seem to suffer from the point of view of rapid indication.

Dr. Millikan offers some suggestions toward simplifying the power-on testing. Our procedure has been not to make any preliminary assumptions as to magnitudes involved. In effect propeller tests are made along with the moment and lift measurements. It has been found that the thrust loading coefficient T_c is quite significant. The pitching moment is substantially proportional to the thrust coefficient at any one angle of attack. Also, the same moment is obtained at the same thrust coefficient regardless of the propeller-pitch setting. This reduces the testing at different pitch settings.

The suggestion made in the paper for analyzing the data will be most helpful, but I wonder whether the discussion of power-on conditions is not so new that we have not yet made up our minds as to what we need. Dr. Millikan has wisely limited his discussion to pitching moments but there are equally significant effects in roll and yaw. It has often been difficult to reconcile a pilot's description of what happens in an airplane with the model test data. Power-on characteristics furnish a clue. When we extend our consideration to the power-on dynamic effects, an unexplored field opens.

The testing of models involving a considerable expense would not be of the fullest benefit if an attempt were not made to show the relation of the results to the general phenomena. In the rush of current work it is often impossible to make as full an analysis as might be desired even in the laboratories. The derivation of equations involving coefficients which can be found with relatively small labor will be helpful in this work.

The important problems now relate to high powers and high speeds. The old rules have gone beyond their range. Stability has practically vanished in some cases. A closer approach to the solution of the problem results from the inclusion of more of the variables in the tests. Dr. Millikan is to be commended for calling attention to one of the more important of these—the effect of the operating propeller. We may anticipate more power-on tests in the future as a result of this interesting paper.

T. P. Wright

Curtiss-Wright Corporation

In presenting this Third Wright Brothers Lecture, Dr. Millikan has admirably continued the high standard set by his predecessors of 1937 and 1938, Professor B. Melvill Jones and Dr. Hugh Dryden. Their papers dealt with questions of airflow in the boundary layer over exposed surfaces. Such matters as turbulent flow and the factors affecting the location of the transition point, separation point, and like phenomena were outlined. Stimulating discussions, including speculations as to the effect on performance of complete laminar flow, were induced by these papers. Now Dr. Millikan has discussed for us the equally important subject of stability and how it is affected by the propeller slipstream. He very neatly pointed out the particular appropriateness of this discussion for a Wright Brothers Lecture, noting that the Brothers Wright first gave the world "power driven flight," hence the propriety of the present lecture commemorating their work, involving "power driven flight for the model."

Aeronautical science and airplane design have progressed to such a stage that we must begin to think of the limits which confront us in the attainment of further performance gains and flying characteristics improvements. Approach to limits implies the increasing need for introducing refinements in calculations and in laboratory procedure, unnecessary at an earlier stage when basic considerations of larger magnitude overshadowed their effect. Thus at present in design we must eliminate such minor obstructions to flow as rivet heads, unimportant in the past, but vital now in reducing drag; similarly, now we must think of simulating airplanes completely in the wind tunnel, even to the extent of including the running propeller and resultant slipstream in order accurately to pre-determine full scale stability characteristics.

As Dr. Millikan brings out in his lecture, design changes such as increasing wing loading have contributed toward this need be-

cause of the envelopment of a greater portion of the wing in the slipstream. He has shown for one case that the magnitude of the slipstream effect is indicated by the need for moving the rearward C.G. forward fifteen percent of the chord in order to obtain a similar stability in the presence of the slipstream to that which would maintain without propellers operating.

I believe no aeronautical engineer who has produced designs in the past can claim a perfect record of turning out prototypes which could go into production without some change in tail surfaces in order to make entirely satisfactory some condition of control or stability. In all probability, a great many of these incorrect initial designs were brought about by improperly projecting wind tunnel test results to full scale, due to changes in behavior when testing without propellers as against full scale tests in the presence of a slipstream. The knowledge to be gained by the application of results of powered models should largely eliminate the necessity for these expensive prototype changes in the future.

In this respect, it is particularly pleasing to note the detailed attention Dr. Millikan has given to the fundamental theory involved which, when backed up by additional tests so that values can be properly assigned to constants, will make possible in the future more accurate stability estimates, even perhaps without recourse to powered models in all cases. However, it is likely that now that Dr. Millikan and his associates have led the way, many of us will follow by securing necessary equipment and, in the future, conducting our tunnel tests of models in the presence of their own slipstream.

His allusion to the possible need of controllable pitch propellers for those models, because of difference in the slipstream due to variations of propeller blade angle, indicates an intriguing detail design problem.

We have indeed been privileged to hear Dr. Millikan present this paper, outlining in such detail the equipment problems involved in conducting wind tunnel tests with models equipped with running propellers together with the calculations needed, properly and scientifically to coordinate the work of the laboratory and design office.

In his concluding paragraph, he refers to the need for further data and tests, offering a "note of interrogation" similar to that with which the two previous Wright Brothers lecturers also concluded. This is to me encouraging from the standpoint of showing the vast field still open for exploration in the aeronautical sciences. We are fortunate to be engaged in an art which is ever expanding. I am reminded of the motto carved above the doorway of a leading store in Los Angeles which reads: "To build a business that shall never know completion."

AUTHOR'S CLOSURE

I am extremely grateful both for the kind remarks which have been made about the paper and for the important suggestions contained in the discussions. Mr. Caldwell's remarks suggest what I am sure all wind-tunnel workers will regard as a hideous possibility. The experimental problems involved in small scale model studies of counter-rotating propellers would appear to be formidable although probably not insuperable. If such propellers are widely adopted these problems will certainly have to be faced.

Dr. Hunsaker objects to the omission of any reference to the classical dynamical stability equations in the paper. I quite agree that an exhaustive discussion of the effects of power on airplane characteristics must include a consideration of all of the stability derivatives of the airplane. Lack of time only has prevented such a discussion, and the influence of power on the longitudinal stability derivatives is currently being investigated. At the moment I can only point out that the pitching moment slope considered in the paper does in some way include the effect of M_u, because of the variation of power with C_L (*i.e.* V) which the suggested operating procedure introduces into the moment coefficient results. In considering suitable subject matter for the present paper the question of the stability derivatives was included but it was decided to omit any reference to dynamic stability, largely because of investigations by the N.A.C.A. which failed to reveal any close correlation between the results of flight tests on stability characteristics and conclusions drawn from solutions of the classical dynamic stability equations. In terms of Dr. Hunsaker's analogy I should, therefore, say that my fishing tackle has been carefully chosen for catfish rather than trout, since a close inspection of the fishpond had indicated that there were in fact no trout present.

In connection with Mr. Wood's remarks I agree that our solution of the tachometric problem is somewhat cumbersome, although it has proved entirely satisfactory in practice. A direct and instantaneously reading tachometer of sufficient accuracy would be of great value to the wind tunnel operator. I am inclined to doubt the desirability of installing torque meters inside models of the size considered in the paper. The electrical method of calibrating and measuring power output has proved so accurate and simple that the complications introduced by dynamometers inside the model would seem hardly justifiable.

Mr. Wright's comments emphasize an aspect of the problem which was insufficiently dealt with in the paper; namely, the correlation of the wind-tunnel results with actually observed full scale characteristics. The importance of such correlations, especially in connection with power effects, cannot be overemphasized.

In conclusion I should like again to thank the discussors for their contributions to this as yet nearly unexplored field.

Vibration of Crankshaft-Propeller Systems. New Method of Calculation

M. A. BIOT

Columbia University

ABSTRACT

The calculation of torsional oscillations in crankshaft-propeller systems is carried out by a new method which reduces considerably the numerical work in the case of in-line engines. The theory is briefly outlined and the reader is referred to another publication of the author for further details. Three applications follow. In the first, all six natural frequencies and the corresponding modes are calculated for a V-12 engine. In the second example the method is adapted to the direct determination of the fundamental frequency. The third example deals with a 12-cylinder flat opposed engine coupled to a blower and through gears to a propeller; all eight natural frequencies are determined. The natural frequencies are determined by plotting a simple curve generally close to a straight line and the corresponding modes of oscillation in the crank are expressed in terms of a sine function. The amount of numerical work involved in the procedure is independent of the number of cylinders of the engine.

INTRODUCTION

AS REGARDS torsional oscillations, an internal combustion engine with a long crankshaft is generally considered to be equivalent to a uniform shaft carrying equidistant identical discs.

The procedures for deriving this equivalent system are familiar to vibration technicians. It is easy to calculate the discs; the moment of inertia of each is proportional to the average rotational inertia of each crank with the attached alternating masses. There will be as many discs as there are cranks. The calculation of the torsional rigidity of the equivalent shaft is not as straightforward. The crankshaft being a rather complicated elastic structure, it is generally difficult to evaluate exactly its average torsional rigidity. Moreover, it will depend on the bearing clearances. A practical rule is to adopt a shaft of the same length and diameter as the crankshaft, and, depending on one's judgment and experience, to vary this length slightly in accordance with bearing clearances, web rigidity,[1] etc. The system is thus reduced to a shaft carrying a certain number of discs.

The various numerical methods devised to calculate the torsional oscillation of such a system become extremely tedious if the number of cranks exceed four. The object of the present paper is to show that it is possible to introduce considerable simplification in this numerical work.

THEORY

Let n be the number of discs representing the crankshaft, I their moment of inertia, and k the torsional spring constant between these discs. Number the discs from 1 to n, and call θ_x the amplitude of oscillation of the disc numbered x (Fig. 1). The amplitudes of oscillation of three successive discs satisfy the equation

$$\theta_{x+1} - \left(2 - \frac{I}{k}\omega^2\right)\theta_x + \theta_{x-1} = 0 \qquad (1)$$

where $\omega/2\pi$ is the frequency of the oscillation.

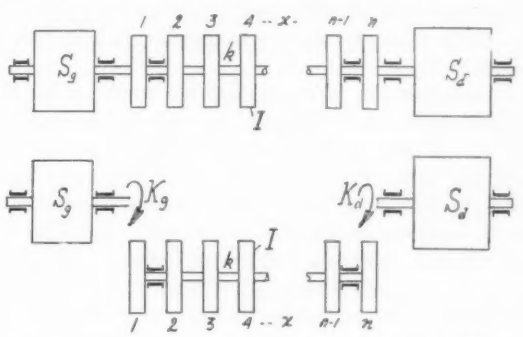

FIG. 1. Schematic representation of a crankshaft and its end impedances.

Setting

$$\omega = 2\sqrt{k/I}\,\sin\mu/2 \qquad (2)$$

it can be verified that Eq. (1) is satisfied by the solution

$$\theta_x = A\cos\mu x + B\sin\mu x \qquad (3)$$

in which A and B are arbitrary constants. These arbitrary constants are determined by the two relations

$$\begin{aligned}\theta_2 - \left(1 - \frac{I}{k}\omega^2 - K_g/k\right)\theta_1 &= 0\\ \theta_{n-1} - \left(1 - \frac{I}{k}\omega^2 - K_d/k\right)\theta_n &= 0\end{aligned} \qquad (4)$$

which govern the motion of the discs at the ends of the shaft. Eqs. (4) involve the mechanical impedances K_g and K_d (Fig. 1) of those parts of the engine which are coupled to the discs number 1 and number n, respectively. The method for calculating these impedances, which are in general functions of the frequency, will be shown in connection with the numerical examples below.

The substitution of the general solution (3) into Eqs. (4) leads to the conditions

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$$A\left[1+\left(\frac{K_g}{k}-1\right)\cos\mu\right]+B\left(\frac{K_g}{k}-1\right)\sin\mu = 0$$

$$A\left[\cos\mu(n+1)+\left(\frac{K_d}{k}-1\right)\cos\mu n\right]+ \quad (5)$$

$$B\left[\sin\mu(n+1)+\left(\frac{K_d}{k}-1\right)\sin\mu n\right]=0$$

By elimination of A and B one obtains the frequency equation,

$$\sin\mu(n+1)+\left(\frac{K_g+K_d}{k}-2\right)\sin\mu n+$$

$$\left(\frac{K_g}{k}-1\right)\left(\frac{K_d}{k}-1\right)\sin\mu(n-1)=0 \quad (6)$$

This equation contains the unknown frequency $\omega/2\pi$ in the variable μ and in the end impedances K_g and K_d. The number of cranks n enters as a parameter. The reader will find a more detailed derivation of Eq. (6) and further information on mechanical impedances in reference 2.

In principle, in order to find the roots of the frequency equation (6) it would be sufficient to plot the left side of the equation as a function of μ or ω and note the value of the abscissa where the curve intersects the horizontal axis. This procedure, however, is rather cumbersome because the function to be plotted goes through many oscillations and requires the calculation of a great number of points. This difficulty is avoided by introducing the complex quantities

$$e^{\frac{\mu i}{2}}+\left(\frac{K_g}{k}-1\right)e^{-\frac{\mu i}{2}}=A_g e^{\phi_g i}$$

$$e^{\frac{\mu i}{2}}+\left(\frac{K_d}{k}-1\right)e^{-\frac{\mu i}{2}}=A_d e^{\phi_d i} \quad (7)$$

The left side of Eq. (6) is then the imaginary part of $A_g A_d e^{(\mu n+\phi_g+\phi_d)i}$. An equivalent form of the frequency equation (6) is therefore

$$\mu n+\phi_g+\phi_d = \text{multiple of } \pi \quad (8)$$

The quantities ϕ_g and ϕ_d are functions of μ or ω defined by Eqs. (7). Their values are

$$\phi_g=\tan^{-1}\left[\left(\frac{2k}{K_g}-1\right)\tan\frac{\mu}{2}\right]$$

$$\phi_d=\tan^{-1}\left[\left(\frac{2k}{K_d}-1\right)\tan\frac{\mu}{2}\right] \quad (9)$$

The practical advantage of Eq. (8) over Eq. (6) resides in the fact that the left side $\mu n+\phi_g+\phi_d$ plotted as a function of μ is a curve generally near to a straight line. The form (8) of the frequency equation is therefore well fitted for a solution by graphical methods or interpolation. It is sufficient to plot the curve in the range between $\mu = 0$ and $\mu = 180°$.

It is also of importance to the designer to know not only the frequencies of the natural oscillations, but to estimate their respective danger as regards resonance stresses. This is done by calculating the energy input of the pressure cycles in each mode. The energy input depends on the Fourier harmonics of the pressure cycle, the firing order of the engine and the shape of the torsional modes in the crankshaft. These shapes are easily obtained from the general solution, Eq. (3) and conditions (5). The angular amplitude of the crank numbered x is

$$\theta_x = C\sin(\mu x+\beta) \quad (10)$$

where β is defined by the relation

$$\tan\beta=\frac{(1-K_g/k)\sin\mu}{1+(K_g/k-1)\cos\mu} \quad (11)$$

The constant C is arbitrary. The torsional mode of order r is found by substituting in these formulas the values μ_r and ω_r corresponding to that mode.

Applications

Example 1

A V-12 engine is represented schematically in Fig. 2. It is coupled directly to a propeller through a shaft of spring constant k_1. The moment of inertia of the propeller is I_1. The numerical values are

$I = .415$ lb. in. sec.^{2}
$I_1 = 162$ lb. in. sec.^{2}
$k = 5.10$ times 10^6 lb. in. per rad.
$k_1 = 2.05$ times 10^6 lb. in. per rad.
$n = 6$

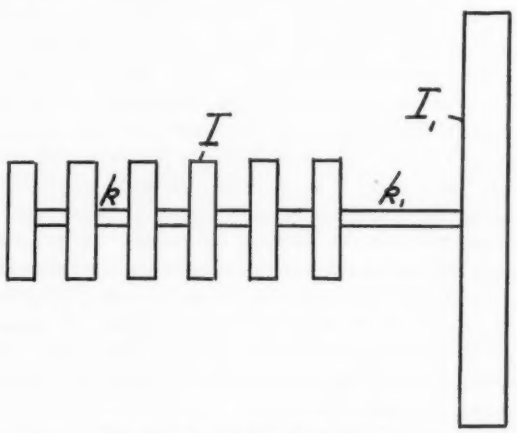

Fig. 2. V-12 engine with propeller.

The moment of inertia I_1 being very large compared to $6I$, it is assumed that the propeller does not oscillate.* The mechanical impedance on the propeller side is therefore reduced to $K_d = k$, *i.e.*, it is equal to the spring constant of the propeller shaft itself. From Eq. (9),

*In all examples treated here the propeller is assumed to be rigid. The influence of propeller elasticity will be taken up in a subsequent paper.

$$\phi_d = \tan^{-1}\left[\left(\frac{2k}{k_1} - 1\right)\tan\frac{\mu}{2}\right] \qquad (12)$$

On the left the crankshaft is free so that $K_g = 0$; hence $\phi_g = 90°$ is a constant. Expressing all angles in degrees,

μ	ϕ_d	$6\mu + \phi_g + \phi_d$
0	0	90
15	27.2	207.2
30	46.2	316.2
45	58.2	418.2
60	66.0	516.0
75	71.3	611.3
90	75.6	705.8
120	81.6	891.6
150	86.0	1076.0
180	90.0	1260.0

The values $6\mu + \phi_g + \phi_d$ are plotted as functions of μ in Fig. 3. The intersections of this curve with

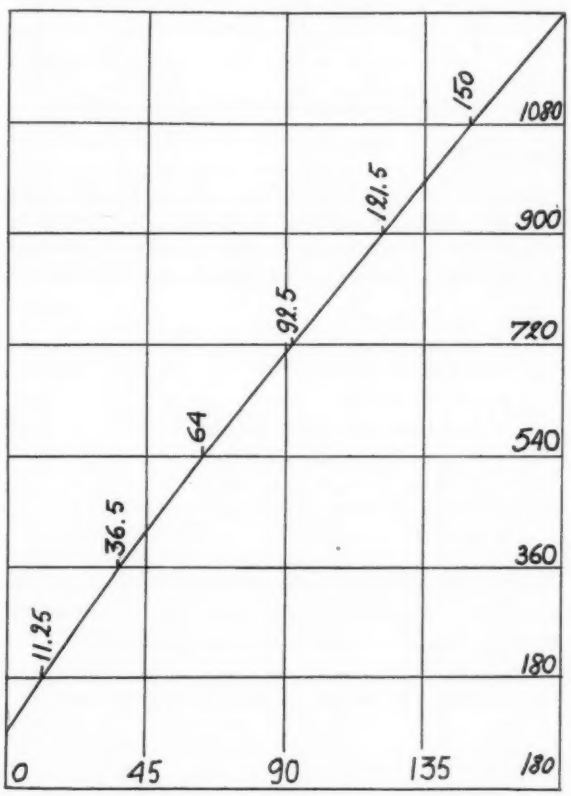

FIG. 3. Graphical determination of the natural frequencies of the engine in Fig. 2 by plotting $6\mu + \phi_g + \phi_d$ as a function of μ.

the horizontals of ordinates 180°, 2 × 180°, 3 × 180°, . . . etc., yield six roots of the frequency equation (8). These roots are the abscissas of the points of intersection and their values in degrees are

$\mu_1 = 11.25$ $\mu_2 = 36.5$ $\mu_3 = 64$
$\mu_4 = 92.5$ $\mu_5 = 121.5$ $\mu_6 = 150$

The corresponding natural frequencies are derived from Eq. (2). In cycles per minute,

$$f_r = \frac{60}{\pi}\sqrt{\frac{k}{I}}\sin\frac{\mu_r}{2}$$

$f_1 = 66800 \sin 5.64 = 6560$ per min.
$f_2 = 66800 \sin 18.25 = 20{,}900$ per min.
$f_3 = 66800 \sin 32.0 = 35{,}400$ per min.
$f_4 = 66800 \sin 46.2 = 48{,}200$ per min.
$f_5 = 66800 \sin 60.7 = 58{,}300$ per min.
$f_6 = 66800 \sin 75.0 = 64{,}500$ per min.

From Eqs. (10) and (11) the shape of the torsional modes are derived. Since $K_g = 0$, $\tan\beta = \sin\mu/(1 - \cos\mu) = 1/\tan(\mu/2)$; hence $\beta = (\pi - \mu)/2$. The shape of the r^{th} mode is therefore

$$\theta_x = \cos\mu_r(x - {}^1/_2); \quad x = 1, 2, \ldots . 6$$

The shape of all six modes is given in the following table and represented in Fig. 4.

	1st Mode	2nd Mode	3rd Mode	4th Mode	5th Mode	6th Mode
θ_1	.995	.949	.848	.692	.489	.258
θ_2	.956	.576	−.104	−.743	−.999	−.707
θ_3	.881	−.024	−.939	−.642	.544	.965
θ_4	.785	−.615	−.719	.798	.438	−.961
θ_5	.633	−.961	.309	.573	−.994	.694
θ_6	.469	−.933	.990	−.838	.601	−.258

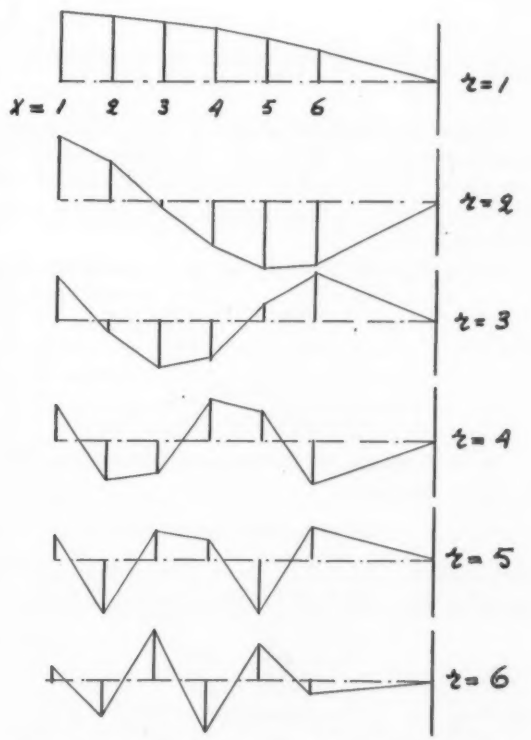

FIG. 4. The six torsional modes of the engine in Fig. 2.

It will be noticed that the problem is simplified if the spring constant of the propeller shaft is equal to k. Putting $k_1 = k$,

$$\phi_d = \tan^{-1} [\tan (\mu/2)] = \mu/2$$

and the expression $6\mu + \phi_d + \phi_g = 6\mu + {}^1/_2\mu + 90°$ plotted as a function of μ comes out as a straight line In this case the roots μ_r are

$$\mu_r = (2/13)(r - {}^1/_2)\pi; \quad r = 1, 2, \ldots\ldots 6$$

Example II

Consider the same engine and propeller as in the previous case but with a drive shaft of low rigidity (Fig. 5). The numerical values are

$I = .415$ lb. in. sec.^{2}
$I_1 = 162$ lb. in. sec.^{2}
$k = 5.10$ times 10^6 lb. in. per rad.
$k_1 = .46$ times 10^6 lb. in. per rad.
$n = 6$

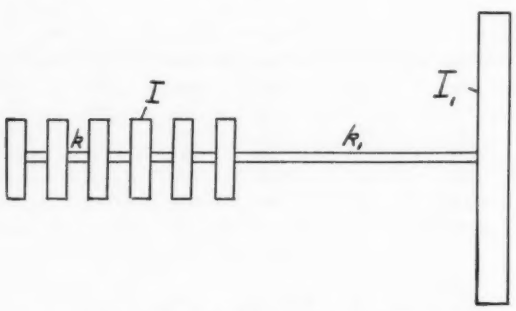

FIG. 5. V-12 engine with propeller and extension drive shaft.

One may be interested primarily in the fundamental frequency which in this case is low compared to the harmonics. It is possible to take advantage of this fact to calculate the fundamental mode directly in the following way.

Putting $K_g = 0$, $K_d = k_1$, Eq. (6) is put in the form

$$\lambda I\omega^2 = k_1$$

with

$$\lambda = \frac{\sin \mu n}{2 \sin (\mu/2) \cos \mu (n - {}^1/_2)}$$

For small values of μ, λ is approximately equal to n. Hence in this case,

$$6I\omega^2 = k_1 \text{ (approximately)}$$

This equation could have been obtained directly by assuming the crankshaft to behave as a rigid body.

$$\omega_1 = \sqrt{\frac{k_1}{6I}} = 428$$

and from Eq. (2) the corresponding value of μ is

$$\mu_1 = 7.0°$$

Substituting this value of μ_1 in λ,

$$\lambda = 7.02$$

and therefore a second approximation is

$$\omega_1 = \sqrt{k_1/7.02I} = 397; \quad \mu_1 = 6.5°$$

This second approximation is quite satisfactory. The fundamental frequency is

$$f_1 = 30\omega_1/\pi = 3800 \text{ per min.}$$

The shape of the fundamental mode is derived from Eq. (10), in which $\mu_1 = 6.5°$ is substituted, and $\beta = (\pi - \mu)/2$. This mode is represented in Fig. 6.

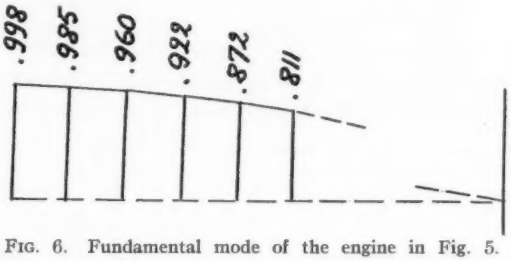

FIG. 6. Fundamental mode of the engine in Fig. 5.

Example III

Consider a 12-cylinder flat opposed engine with propeller, reduction gear, and blower. The system is represented schematically in Fig. 7. The numerical values corrected to crankshaft speed are as follows*:

$I = .65$ lb. in. sec.^{2}
$I_1 = .49$ lb. in. sec.^{2}
$I_2 = 155$ lb. in. sec.^{2}
$I_3 = 5.95$ lb. in. sec.^{2}
$k = 10.5$ times 10^6 in. lb. per rad.
$k_1 = 8$ times 10^6 in. lb. per rad.
$k_2 = .6$ times 10^6 in. lb. per rad.
$k_3 = .05$ times 10^6 in. lb. per rad.
$n = 6$

The reciprocal of the mechanical impedance K_d corresponding to the propeller and gears may be calculated as a function of μ through the following steps

* The author is indebted for the data on this engine to Mr. L. S. Hobbs and Mr. Williams of Pratt and Whitney Aircraft.

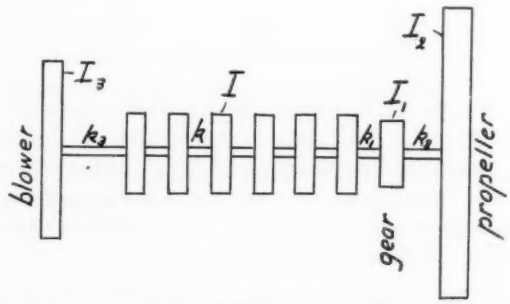

FIG. 7. 12 cylinder flat opposed engine with gear propeller and blower.

$$\omega^2 = \frac{4k}{I}\sin^2\frac{\mu}{2}$$

$$\frac{1}{K_d''} = \frac{1}{k_2} - \frac{1}{I_2\omega^2}$$

$$K_d' = K_d'' - I_1\omega^2$$

$$\frac{1}{K_d} = \frac{1}{k_1} + \frac{1}{K_d'}$$

The impedance on the blower side is given by

$$\frac{1}{K_g} = \frac{1}{k_3} - \frac{1}{I_3\omega^2}$$

The corresponding functions ϕ_g and ϕ_d defined by Eqs. (9) are then calculated.

Before doing this, however, it is convenient to take advantage of the fact that approximate values for the two lower frequencies are easily found. The fundamental frequency corresponds to an oscillation of the blower while the engine and propeller stay fixed. This gives

$$\omega_1 = \sqrt{k_3/I_3} = 91.7; \quad f_1 = 876 \text{ per min.}$$

and the corresponding value of μ is $\mu_1 = 1.30°$
The next frequency corresponds to an oscillation of the mass $6I + I_1$ as a rigid system while the propeller and the blower stay fixed. Due to the low value of k_3 the influence of the blower on this frequency is negligible. The second frequency is therefore approximately

$$\omega_2 = \sqrt{\frac{k_2}{6I + I_1}} = 370; \quad f_2 = 3530 \text{ per min.}$$

and the corresponding value of μ is

$$\mu_2 = 5.30°$$

Having obtained approximate values for the two lower roots the calculation of ϕ_g and ϕ_d in the range $0 < \mu < 15°$ is limited to three points in the vicinity of each value μ_1 and μ_2. The functions are given in the following table.

μ	ϕ_g	ϕ_d	$6\mu + \phi_g + \phi_d$
0	−90	−90	−180
1.25	−25.5	11.75	− 6.3
1.30	− 7.1	12.9	13.6
1.35	13.8	14.1	36.0
4	85.6	52.2	161.8
5	86.6	59.5	176.1
6	87.2	66.3	189.5
15	88.9	88.7	267
30	89.5	107	376
45	90	124	484
60	90	144	594
75	90	169	709
90	90	194	824
120	90	231	1041
150	90	253	1243
180	90	270	1440

The quantity $6\mu + \phi_g + \phi_d$ is plotted as function of μ in Fig. 8. The roots determined graphically are

$\mu_1 = 1.268$ $\mu_2 = 5.30$ $\mu_3 = 27.8$ $\mu_4 = 53$
$\mu_5 = 77$ $\mu_6 = 101$ $\mu_7 = 126$ $\mu_8 = 152$

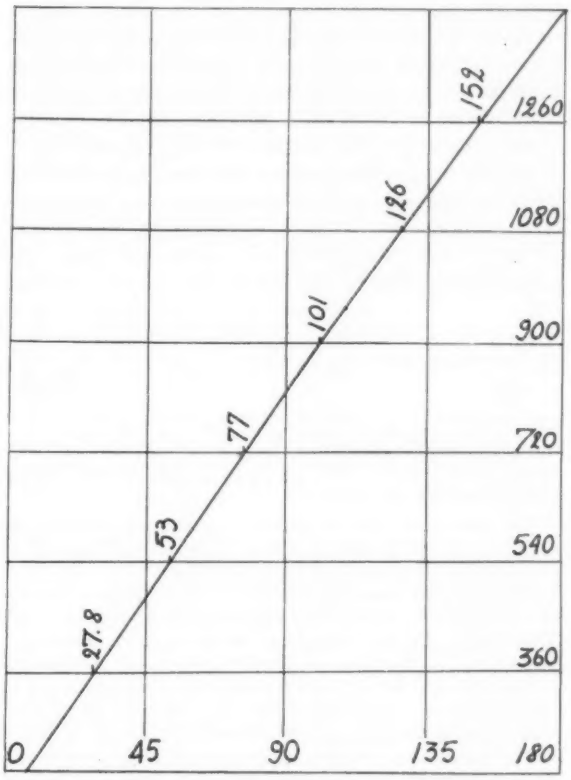

FIG. 8. Graphical determination of the natural frequencies of the engine in Fig. 8 by plotting $6\mu + \phi_g + \phi_d$ as a function of μ. The curve is not plotted in the range $0 < \mu < 6°$ and the two lower roots μ_1 and μ_2 do not appear in the diagram.

The corresponding frequencies in cycles per min. are:

$f_1 = 76800 \sin .634 = 846$ per min.
$f_2 = 76800 \sin 2.65 = 3540$ per min.
$f_3 = 76800 \sin 13.9 = 18500$ per min.
$f_4 = 76800 \sin 26.5 = 34200$ per min.
$f_5 = 76800 \sin 38.5 = 47700$ per min.
$f_6 = 76800 \sin 50.5 = 59200$ per min.
$f_7 = 76800 \sin 63 = 68400$ per min.
$f_8 = 76800 \sin 76 = 74500$ per min.

A complete plot of the curve $6\mu + \phi_g + \phi_d$ would show that it is not as near to a straight line in the range $0 < \mu < 6°$. However in the range $1.25° < \mu < 1.35°$ and $4° < \mu < 6°$ it is practically straight so that μ_1 and μ_2 may be determined quite accurately by linear interpolation.

CONCLUSION

A simple expression (Eq. (6)) has been developed for the natural frequencies of torsional oscillation of a

crankshaft-propeller system. In this equation the number of cranks appears as a parameter. A further simplification resides in the possibility of determining the roots of this equation graphically by plotting a curve (Eq. (8)) which is near to a straight line and therefore requires the calculation of only a few points. Once the frequencies are found it is easy to determine the energy input in each mode since the shape of each mode in the crank is expressed by means of a simple sine function (Eq. (10)). An idea of the rapidity of the method is given by the fact that the calculation of the six natural frequencies and their corresponding modes in Example I takes about one and a half hours of slide rule work. This is considerably faster than by any other method. Other advantages are: the necessary smoothness of the plotted curve furnishes an immediate check on any numerical error; the amount of numerical work is independent of the number of cylinders; possibility of calculating the new frequencies due to a separate change in propeller, crankshaft, or blower, without having to repeat all of the computations; possibility of taking advantage of an approximate guess of certain frequencies. The method is also applicable as such to engines with double identical crankshafts in parallel.

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[1] Den Hartog, J. P., *Mechanical Vibrations*, page 205; McGraw-Hill Book Co., 1934.

[2] v. Kármán, Th., and Biot, M. A., *Mathematical Methods in Engineering*, Chapter XI, Section 6; McGraw-Hill Book Co., 1940.

[3] Lürenbaum, Karl, *Vibration of Crankshaft-Propeller Systems*, S.A.E. Journal, Vol. 39, pages 469–479, December, 1936.

Book Reviews

Applied Aerodynamics, by Leonard Bairstow; Longmans, Green and Company, New York and London, second edition, 1939; 808 pages, $18.50.

The appearance of a comprehensive text by so renowned an authority as the Zarahoff Professor of Aviation, University of London, deserves special notice. Dr. Bairstow is also Vice-Chairman of the Aeronautical Research Committee and Director of the School of Aeronautics, Imperial College of Science and Technology. He was formerly in charge of the Aerodynamics Department of the National Physical Laboratory, Teddington, and with the late Dr. T. E. Stanton, played an important part in the establishment of the wind tunnel as a tool of the airplane designer, during the years preceding World War I. Dr. Bairstow will be best known, perhaps, to the modern generation of aeronautical engineers for his pioneer work on dynamical stability of airplanes and airships, for his step by step integration of the disturbed or controlled motion of aircraft in maneuvers, and for the first edition of this text in 1919, the first comprehensive treatise on Applied Aerodynamics in the English language.

Needless to say, Applied Aerodynamics in 1939 is such a vastly expanded field that this 1939 edition is practically a new book. Since the fundamental facts and principles were already pretty clear in 1919, the exposition in some chapters of the new edition follows the theoretical development of the first edition, but is illustrated with examples taken from modern practice. However, entirely new branches of aerodynamic science have appeared since 1919, such as the theory of the finite airfoil, theoretical forms of airfoil, vortex theory of propellers, boundary layer mechanics, effects of turbulence, effects of compressibility, transition and separation in airflow, theory of the spin and of flutter. Likewise, new devices have created new problems, and new and refined methods of aerodynamic experimentation have been developed. I might mention, offhand, the following, that could have been but dimly foreseen in 1919: variable density, sonic, low turbulence, spinning, free flight, gust, and full scale wind tunnels; hot wire anemometers; oscillograph and microphone apparatus; high-lift devices; feathering and governed propellers; automatic pilots; rotating wings; ducts and cowls, and so on.

In 1919, Dr. Bairstow accomplished the monumental task of developing a comprehensive text which extracted the principles of flight from the mass of detailed information available after the War. Now in 1939, on the eve of a new War, Dr. Bairstow has repeated his task. The information to be organized is now immensely more extensive and world-wide in its sources.

The text under review is comparable in scope to Durand's six-volume Aerodynamic Theory written by many specialists. Its price, therefore, considered in comparison with several volumes, is astonishingly low. It is both a text for the student and a reference work of theory and method.

It is distinctly not a handbook, as its specific data are selected to illustrate or substantiate the exposition. While there are hundreds of tables, figures, and plates, each is brought forward in connection with the text. A good deal of compression and even some omissions were necessary to achieve its two-inch thickness against the six inches of Durand's set of books. It seems fair to state that Bairstow's book gains in logical development of its topics by being written by a teacher with a definite plan of exposition in mind, but loses considerable in clarity by the very nature of the degree of compression required to cover the field. For example, Bairstow treats propeller theory and design in 79 pages, while in Volume IV of Durand, Glauert is allowed 191 pages on theory and design with 69 pages more for Koning on interference, or a total of 260 pages. Naturally the longer treatment is easier to read, but the Bairstow treatment is a more ready reference for a method of computation.

The function of a review is to tell what a book contains and to give an opinion of its merits. As embroidery, a reviewer is also permitted to air some of his own notions in the form of criticism.

To present the last item first, this reviewer finds the book somewhat lacking from the point of view of the student who initially approaches aerodynamics with this text as a guide. For example, this student will find no specific mention of the Momentum Theorem, but he will see it used informally in several places. Momentum is not to be found in the index.

Bernoulli's equation is listed but once in the index, for page 351, where the name is applied to an equation arrived at incidentally as one form for the dynamical equations of motion of an ideal fluid. There is no hint that a man named Bernoulli was the father of hydraulics, nor that the equation given his name is universally used by practical men, nor that the equation has several restrictions in its applicability to real fluids.

Likewise the Pitot tube is described on page 82 without historical reference to its name. The relation between p and v is given as an experimental fact. Only later in the text could the student discover, if he be acute, that the dynamic pressure in the tube looks as if Bernoulli's equation had something to do with it.

The difficulty I point out is inherent in Dr. Bairstow's scheme of first presenting the experimental facts and later taking up the

theory. There seems to be nothing to tie them together, except a good tutor. Perhaps Dr. Bairstow does not intend his text for self instruction.

Other criticisms are probably matters of taste. I think the treatment of "Dynamical Similarity and Scale Effects" is less than adequate. Reynolds Number is arrived at by consideration of some elaborate differential equations of motion which the student can find later on in the book, if he does not skip that chapter on account of mathematical deep water. The Reynolds Number is also found alternatively by dimensional reasoning. This latter presentation is so simple, it may look like sleight of hand. However, the theory of dimensions is a powerful method for the experimenter, and it seems a pity that the student is not given a broader discussion of non-dimensional coefficients, including Buckingham's Pi Theorem.

Dr. Bairstow has evidently compressed his material to a degree that leaves out the historical approach to the problems treated. Thus on page 428, at the beginning of a long chapter on the Airfoil of Finite Span, the only reference to the pioneers of the greatest modern contribution to applied aerodynamics is made in six words: "attributed independently to Lanchester and Prandtl." This is hardly fair to the pioneers or to the student.

However, Dr. Bairstow is pleasantly inconsistent in that he very properly points out in a footnote on page 267 the importance of Lord Rayleigh to the modern method of dealing with model tests by the principle of dimensions.

As to the selection of material to be discussed, Dr. Bairstow must often have been puzzled to choose between compression and omission. It is likely that he has used his own experience as a teacher in his decisions. Those matters that are not yet very clearly understood and are, therefore, difficult for the teacher to treat adequately, tend to be omitted entirely. For example, I find nothing about the aerodynamic effects of roughness of wing surfaces, the location of the transition point, or the effect on wing drag of relative areas subject to laminar and turbulent flow. The word transition is not in the index.

Nor can I find any reference to heat transfer and cooling problems. It can be appreciated that the connection between heat transfer and fluid friction presents difficulties, but the work of Prandtl, G. I. Taylor, Dryden, and von Kármán, stemming from Osborn Reynold's original analogy, surely is an important aspect of modern applied aerodynamics.

Turning aside from such criticisms, which are trivial compared with the scope of the book, I quote the Table of Contents as the best outline of its great value as a text (with teacher) and as a reference work.

CHAPTER I. OUTLINES OF THE DEVELOPMENT OF THE SUBJECT OF APPLIED AERODYNAMICS.

CHAPTER II. THE PRINCIPLES OF FLIGHT.
- II. 1. The Aeroplane; Forces in Steady Flight.
- II. 2. Longitudinal Balance.
- II. 3. The Flying-Boat.
- II. 4. The Autogyro.
- II. 5. Lighter-Than-Air Craft.

CHAPTER III. GENERAL DESCRIPTION OF METHODS OF MEASUREMENT IN AERODYNAMICS AND THE PRINCIPLES UNDERLYING THE USE OF INSTRUMENTS AND SPECIAL APPARATUS.
- III. 1. The Measurement of Air Velocity.
- III. 2. Wind Tunnels and Aerodynamic Balances.

CHAPTER IV. ILLUSTRATIVE EXAMPLES OF LABORATORY TESTS.
- IV. 1. Wings and Other Parts of Aircraft Considered Separately.
- IV. 2. The Complete Aeroplane.
- IV. 3. Experiments on Wing Stalling.

CHAPTER V. AERIAL MANOEUVRES AND THE EQUATIONS OF MOTION.
- V. 1. Some Aerial Manoeuvres.
- V. 2. Equations of Motion with Examples.
- V. 3. More Accurate Development of the Mathematics of the Aerofoil Element Theory.

CHAPTER VI. DYNAMICAL SIMILARITY AND SCALE EFFECTS.
- VI. 1. Similarity.
- VI. 2. General Applications of the Principles of Dynamical Similarity.
- VI. 3. Aeronautical Applications of the Principles of Dynamical Similarity.

CHAPTER VII. FLUID MOTION: PART I.
- VII. 1. Illustrations of Fluid Motion and Elementary Theory for an Inviscid Incompressible Fluid.
- VII. 2. Kinematic Equations of Motion, in Two Dimensions, for an Inviscid Incompressible Fluid.
- VII. 3. Potential Flow; General Mathematical Definition of Potential Flow.
- VII. 4. Potential Flow Round a Circular Cylinder.
- VII. 5. Joukowsky's Transformation.
- VII. 6. Flow Round Joukowsky Aerofoil.
- VII. 7. Dynamic Equations of Motion, in Two Dimensions, for an Inviscid Incompressible Fluid.
- VII. 8. Collection of Formulae for Joukowsky Aerofoils of Any Section and an Application to Thin Aerofoils.
- VII. 9. Forces and Moments on an Aerofoil or Other Cylinder Moving through an Inviscid Fluid; Effects of Translation, Circulation, Acceleration and Rotation.
- VII. 10. Examples of the Use of the Force and Moment Equations of VII.9.
- VII. 11. The Inclined Flat Plate Considered as the Limit of an Elliptic Cylinder.
- VII. 12. Problems Involving More Than One Plane.
- VII. 13. Vortex Streets.

CHAPTER VIII. THE AEROFOIL OF FINITE SPAN. FLUID MOTION: PART II.
- VIII. 1. Trailing Vortices.
- VIII. 2. Finite Aerofoil of Varying Plan Form and Varying Angle of Incidence.
- VIII. 3. Tapered Wings.
- VIII. 4. Downwash.
- VIII. 5. Wind-Tunnel Interference on a Monoplane Aerofoil of Finite Span.

CHAPTER IX. VISCOUS INCOMPRESSIBLE FLUID IN TWO DIMENSIONS. FLUID MOTION: PART III.
- IX. 1. Equations of Motion.
- IX. 2. Simple Examples of the Use of the Equations of Viscous Fluid Motion.
- IX. 3. Some General Consequences of the Physical Condition That There Is No Slipping of a Viscous Fluid over a Solid Body in Contact with It.
- IX. 4. The Boundary Layer Equations.
- IX. 5. Solutions of the Boundary Layer Equations.
- IX. 6. Applications of Pohlhausen's Solution.

CHAPTER X. THE MOTION OF COMPRESSIBLE INVISCID FLUIDS IN TWO DIMENSIONS. FLUID MOTION: PART IV.
- X. 1. Equations of Motion.
- X. 2. Shock Waves.
- X. 3. The Mathematics of Shock Waves in Two Dimensions.
- X. 4. Details of the Mathematical Theory of Shock Waves.
- X. 5. Aerofoil Theory at Supersonic Speeds.

CHAPTER XI. TURBULENT MOTION. FLUID MOTION: PART V.
- XI. 1. Measurement of Turbulence.
- XI. 2. Reynolds' Modification of the Equations of Motion When Turbulence Exists.

CHAPTER XII. AIRSCREWS.
- XII. 1. General Theory.
- XII. 2. A Working Theory of the Airscrew—The Blade Element.
- XII. 3. Thrust and Torque Coefficients of the Complete Airscrew.
- XII. 4. Experimental Determination of the Thrust and Torque Coefficients of a Family of Airscrews of Variable Pitch.
- XII. 5. Forces and Moments on an Airscrew Which Is Not Moving Axially through the Air.

CHAPTER XIII. REDUCTION AND PREDICTION OF AEROPLANE PERFORMANCE.
- XIII. 1. Standard Atmosphere.
- XIII. 2. Reduction of Flight Observations to Standard Conditions.
- XIII. 3. Prediction of Aeroplane Performance.

CHAPTER XIV. THE STABILITY OF THE MOTIONS OF AIRCRAFT.
- XIV. 1. General Introduction to the Problems Covered by the Term Stability.
- XIV. 2. Mathematical Theory of Stability.
- XIV. 3. The Details of the Disturbed Motion of an Aeroplane.
- XIV. 4. Flutter Theory.

J. C. HUNSAKER
Massachusetts Institute of Technology

Handbook of the War, by JOHN C. DEWILDE, DAVID H. POPPER, and EUNICE CLARK; Houghton Mifflin Company, Boston, 1939; 248 pages, $2.00.

This book gives a complete geographical, military, naval, aerial, economic, and financial picture of the present war. It is a readable, graphic exposition of the hard core of information essential to an enlightened discussion of war and peace in Europe.

Of especial interest to those interested in aviation will be the chapters dealing with air forces and their comparative strengths. It is apparent that the authors have had access to reliable information and have used it with discrimination. In addition to giving an estimate of the present air strength of the leading combatant countries there is a chart showing the probable replacement per month. Other charts give estimates of first line air strengths and bombing times and targets.

The discussion of air strategy from several viewpoints shows careful investigation and gives carefully considered opinion as to the possible use of aircraft during the next year. Emphasis is rightly placed on the paucity of pilots and mechanics as a factor in estimating air strengths.

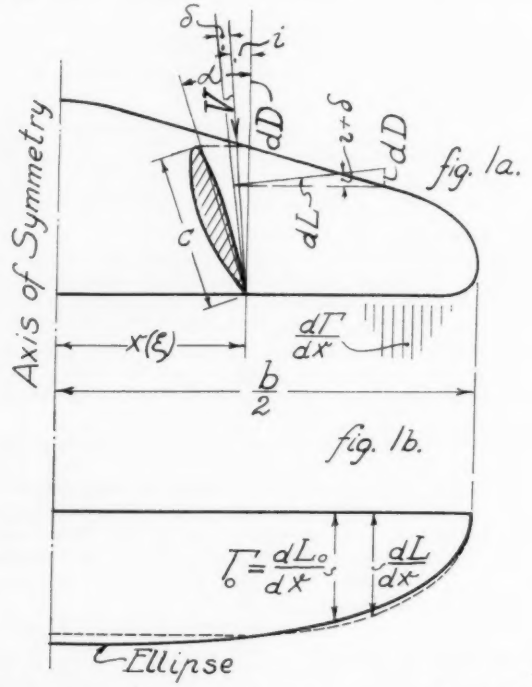
A concluding chapter on the defense of America is an excellent summary of the present military status of the United States.

The Wing of Minimum Total Resistance

H. REISSNER

Armour Institute of Technology

THE wing of minimum induced resistance for a given span and lift was first determined by M. Munk.[1] It is characterized by the property that the induced velocity w perpendicular to the direction of flight velocity V is constant over the span b and, as a consequence, the circulation function Γ is given by an ellipse (Fig. 1b).



This theorem does not take into account the parasite resistance D_p given experimentally by the parasite drag coefficient C_D or the parasite drag angle

$$\delta = C_D/C_L$$

which though it has been diminished considerably by careful surface construction of the wings is still of about the same order of magnitude as the induced resistance D_i especially for high velocities of flight.

It is the purpose of this paper to extend the problem of Munk to a theorem giving the characteristic properties of a wing of minimum total (induced plus parasite) resistance. Such a theorem would have to give the best distribution of induced velocity and the corresponding best lift distribution along the span of a wing if the span b, the total lift L, the velocity of flight V, and the distribution of drag angle δ is prescribed.

As the parasite drag angle δ increases with the thickness ratio of the airfoil and therefore increases toward the middle of the span it will in general not be constant and will have to be deduced from experiments, taking account of the scale of the dimensions and the state of the surface of the wing. Besides it may be mentioned that δ in the range of small angles of incidence α is nearly independent of α and increases outside of it.

The theory given here treats the wing as a fixed vortex line with circulation varying along the span, this variation being produced by a free vortex sheet left behind the trailing edge of the wing.

v. Kármán[2] and R. Fuchs[3] have shown that the theory can be extended to fixed vortex sheets corresponding to the profile of the wing. These papers like that of Munk, are concerned only with the pure induced resistance.

The question whether the theorems found by v. Kármán and by Fuchs can also be generalized for parasite drag, is not treated here.

Induced Velocity Distribution w for Minimum Total Resistance

According to Fig. 1a the resistance dD of an element dx of a wing having a chord c and a downwash angle $i = \tan^{-1} w/V$ may be expressed in terms of the lift dL on this element by

$$dD = dL \sin (i + \delta)$$

and considering that in all practical cases both angles are small,

$$dD = dL(i + \delta)$$

the lift on an element $c\,dx$ depends on the circulation Γ and the drag angle δ as follows:
The lift can be expressed by the lift coefficient and the drag angle

$$dL = c\,dx \frac{\rho}{2} V^2 C_{L_0}(1 - k\delta)$$

where C_{L_0} is the lift coefficient for a frictionless wing (the ideal coefficient)* and, following an investigation

Presented at the Pacific Coast Meeting, I.Ae.S., Pasadena, California, June 16, 1939.

* For the sake of connection with current practice, below the stalling régime the "ideal" lift coefficient is $C_{L_0} = 2\pi(\alpha - i)$ and, using the customary abbreviation $1 - k\delta = \eta$, the lift coefficient appears in the form $C_L = 2\pi(\alpha - i)\eta$, which, though not needed in this paper, would have to be used in the detail design of the wing.

by Wieselsberger, $k\delta$ is the diminution due to the parasite drag, where the number k, in the normal angle range, is about 7.5. The "ideal lift" can be further expressed by the Kutta-Joukowsky theorem:

$$dL_0 = \rho\Gamma V dx$$

The comparison gives

$$dL = \rho\Gamma V dx(1 - k\delta)$$

which when integrated along the length of the span gives

$$L = \rho V \int_{-b/2}^{+b/2} dx\Gamma(1 - k\delta) \qquad (1)$$

$$D = \rho V \int_{-b/2}^{+b/2} dx\Gamma(i + \delta)(1 - k\delta) \qquad (2)$$

The first part of the problem is now to determine such a distribution $i = i(x)$ which for a prescribed lift L and a given distribution of parasite drag $\delta = \delta(x)$ makes the total resistance D of the wing a minimum. The method of Fuchs,[2] which is much simpler than the original method of Munk, is followed. Fuchs uses for the ideal potential flow around a wing the reciprocal theorem of Gauss, which, given two sets of potential functions and normal derivatives for any closed surface A, not containing singularities, has the general form:

$$\int \varphi_1 \frac{\partial \varphi_2}{\partial n} dA = \int \varphi_2 \frac{\partial \varphi_1}{\partial n} dA$$

and for this special case

$$\int_{-b/2}^{+b/2} \Gamma_1 i_2 dx = \int_{-b/2}^{+b/2} \Gamma_2 i_1 dx \qquad (3)$$

In the following as in Eqs. (1) and (2) it will be assumed that the effects of frictional flow may be simply added to the effects of the potential flow. Prandtl and his followers have shown by numerous investigations that this procedure is permissible. Generalizing the method of Fuchs, assume that two sets of correlated circulation and angle functions $\Gamma_1 i_1$ and $\Gamma_2 i_2$ are given in some way and introduce the corresponding set of the differences $\Gamma_1 - \Gamma_2$ and $i_1 - i_2$.

Then the resistance D_d connected with the latter set will be, according to Eq. (2),

$$D_d = \rho V \int_{-b/2}^{+b/2} dx(\Gamma_1 - \Gamma_2)[i_1 + \delta - (i_2 + \delta)]\eta$$

in which small quantities of the third order, such as $\Gamma i\delta$ will be neglected in comparison with those of the second order Γi or $\Gamma\delta$ and $\eta = 1 - k\delta$. Then, since by Eq. (2),

$$D_1 = \rho V \int \Gamma_1(i_1 + \delta)\eta dx \text{ and}$$

$$D_2 = \rho V \int \Gamma_2(i_2 + \delta)\eta dx$$

$$D_d = D_1 + D_2 - \rho V \int dx\Gamma_1(i_2 + \delta)\eta - \rho V \int dx\Gamma_2(i_1 + \delta)\eta$$

Using the reciprocal theorem, Eq. (3), and neglecting again quantities of the third order this last equation becomes:

$$D_d = D_1 + D_2 - 2\rho V \int dx\Gamma_2(i_1 + \delta/2)\eta - \rho V \int dx\Gamma_1\delta\eta$$

If now it is assumed that the induced angle i_1 is such that

$$i_1 + \delta/2 = \lambda \qquad (4)$$

where λ is a small constant, then

$$D_d = D_1 + D_2 - 2\rho V\lambda \int dx\Gamma_2\eta - \rho V \int dx\Gamma_1\delta\eta$$

Then using as the last step the condition that the lift is prescribed and therefore, by Eq (1):

$$L = \rho V \int \Gamma_1 dx\eta = \rho V \int \Gamma_2 dx\eta$$

and neglecting the quantity of the third order $\lambda\Gamma\delta$ against $\lambda\Gamma$ leads to

$$D_d = D_1 + D_2 - 2\rho V \int dx\Gamma_1(i_1 + \delta)\eta$$

and, in line with Eq. (2), the final result is

$$D_2 = D_1 + D_d$$

Thus,

$$D_2 > D_1$$

since D_d, being a resistance, must be positive. This proof is exactly analogous to that of Fuchs.

But this proof is now valid not only for a pure induced resistance but also for an arbitrary given distribution of parasite resistance coefficient, so that the following statement can be made: *The condition for minimum total resistance requires such a distribution of the induced velocity w or the induced inflow angle change i that the sum of the induced inflow angle change and the half of the parasite drag angle $\delta/2$ is constant.*

To satisfy this condition it is necessary to determine the lift distribution dL/dx producing a prescribed inflow angle change $i = \lambda - \delta/2$ and to determine the constant λ from the total lift L of the wing.

Circulation and Lift Distribution for Minimum Total Resistance

The relation between the inflow angle change i and the circulation Γ belonging to a vortex sheet distribution $d\Gamma/dx$ is fixed by the Biot-Savart integral, that is by the following equation:

$$i(x) = -\frac{1}{4\pi V}\int_{-b/2}^{+b/2}\frac{d\xi}{\xi - x}\frac{d\Gamma}{d\xi} \qquad (5)$$

signifying that each vortex filament $d\Gamma$ at the points ξ induces at the point x a velocity perpendicular to the radius $\xi - x$ of an amount equaling $-1/4\pi V$ times the integrand. If now in Eq. (5) the "best" angle distribution i is introduced from Eq. (4), the integral equation for the corresponding "best" circulation Γ (and lift distribution) becomes

$$i = \lambda - \frac{\delta}{2} = -\frac{1}{4\pi V}\int_{-b/2}^{+b/2}\frac{d\xi}{\xi - x}\frac{d\Gamma}{d\xi} \qquad (5a)$$

where the constant λ must be determined by means of the prescribed value of lift according to Eq. (1).

In order to solve the integral equation, Eq. (5a), following the method given by Fuchs,[5] put

$$\xi = -\frac{b}{2}\cos\psi, \quad x = -\frac{b}{2}\cos\varphi$$

The integral in Eq. (5a) then transforms into

$$-\frac{2}{b}\int_0^\pi \frac{d\psi}{\cos\psi - \cos\varphi}\frac{d\Gamma}{d\psi}$$

and Eq. (5a) becomes

$$\lambda - \frac{\delta}{2} = \frac{1}{2\pi bV}\int_0^\pi \frac{d\psi}{\cos\psi - \cos\varphi}\frac{d\Gamma}{d\psi} \qquad (5b)$$

Expanding the circulation Γ into a Fourier series,

$$\Gamma = \sum \Gamma_n \sin(n\psi), \quad \frac{d\Gamma}{d\psi} = \sum \Gamma_n\, n \cos(n\psi) \qquad (6)$$

where the n are odd integers and the Γ_n constants, the definite integral of the right side of Eq. (5b) becomes a well known integral[5] and

$$\frac{\Gamma_n n}{2\pi bV}\int_0^\pi \frac{d\psi\cos(n\psi)}{\cos\psi - \cos\varphi} = \frac{\Gamma_n n}{2bV}\frac{\sin(n\varphi)}{\sin\varphi}$$

then Eq. (5b) appears in the form

$$i = \lambda - \frac{\delta}{2} = \frac{1}{2bV}\sum \Gamma_n n \frac{\sin(n\varphi)}{\sin\varphi} \qquad (5c)$$

(a) By choosing $n = 1$ Munk's elliptical distribution for the circulation results for the case when the drag angle δ is zero or a constant. One has then

$$\Gamma = \Gamma_1 \sin\psi = \Gamma_1\sqrt{1 - (2x/b)^2} \qquad (6a)$$

$$i = \lambda - \delta/2 = \Gamma_1/2bV$$

$$L = \rho V\frac{b}{2}\Gamma_1(1 - k\delta)\int_0^\pi \sin^2\psi d\psi = \frac{\pi b}{4}\rho V\Gamma_1(1 - k\delta)$$

which gives the coefficient Γ_1 in terms of the prescribed lift L, so that

$$\Gamma_1 = \frac{4L}{\pi bV\rho(1 - k\delta)}$$

and

$$\lambda = \frac{\delta}{2} + \frac{2L}{\pi b^2V^2\rho(1 - k\delta)} \text{ or } i = \frac{2L}{\pi b^2V^2\rho(1 - k\delta)} \qquad (7)$$

The angle i must be determined by Eq. (7) in order to find the inclination of the chord of the profile to conform to the distribution of lift.

It is important to point out that the elliptical distribution of lift gives, for a fixed span, not only the minimum induced drag but also the minimum total drag *if the drag angle δ is constant along the span.*

The influence of a uniform parasite drag angle consists therefore only in the change of value of the constant λ given above and in the change of the orientation $\alpha - i$ of the chords of the profiles.

The resistance corresponding to this case is, according to Eqs. (1) and (2)

$$D = (\lambda + \delta/2)L = L\left[\delta + \frac{2L}{\pi b^2V^2\rho(1 - k\delta)}\right] \qquad (8)$$

which gives again as the span of minimum resistance:

$$b = \infty$$

(b) The next simple case would be to choose in Eq. (5c),

$$\Gamma = \Gamma_1 \sin\psi + \Gamma_3 \sin 3\psi \qquad (6b)$$

Then, by Eq. (5c), the induced angle and with it the drag δ (along the span) must follow the law,

$$i = \lambda - \frac{\delta}{2} = \frac{1}{2bV}[\Gamma_1 + 3\Gamma_3(3 - 4\sin^2\varphi)]$$

$$= \frac{1}{2bV}\left[\Gamma_1 - 3\Gamma_3 + 12\Gamma_3\left(\frac{2x}{b}\right)^2\right] \qquad (6d)$$

Since λ is a constant, this result fits the case in which the drag angle δ *decreases parabolically from the middle of the wing span to the tips.* Such a choice of the variation of drag angle along the span seems to be of practical value considering the decrease of parasite drag δ from the middle of the span to the tips due to the decrease of thickness of the profile sections.

Yet *any symmetrical distribution of the drag angle along the span can be realized by the Fourier series in Eq. (5c) with sufficient accuracy.*

Suppose now that to satisfy Eq. (6d) the drag angle distribution is given by

$$\delta = \delta_0 - \delta_1 x^2 \qquad (9)$$

so that at the root section

$$\delta = \delta_0$$

and at the tip section

$$\delta_b = \delta_0 - \delta_1 b^2/4$$

Then Eqs. (6d) and (9) can be written

$$i = \lambda - \frac{1}{2}(\delta_0 - \delta_1 x^2) =$$

$$\frac{1}{2bV}\left[[\Gamma_1 - 3\Gamma_3 + 12\Gamma_3\left(\frac{2x}{b}\right)^2\right]$$

Hence the constants are to be determined from

$$\Gamma_3 = \frac{b^3\delta_1 V}{48},\ \Gamma_1 = bV\left(2\lambda - \delta_0 + \frac{b^2\delta_1}{16}\right)$$

All of the quantities appearing in these expressions must be given except λ which must again be determined by the prescribed value of the lift L.

Therefore the expressions for Γ and δ have to be put into Eq. (1). These expressions are, from Eqs. (6b) and (8),

$$\Gamma = bV\sin\psi\left[2\lambda - \delta_0 + \frac{b^2\delta_1}{8} - \frac{b^2\delta_1}{12}\sin^2\psi\right]$$

$$1 - k\delta = 1 - k\left(\delta_b + \frac{b^2}{4}\delta_1\sin^2\psi\right)$$

Eq. (1) then reads

$$L = \rho V^2\frac{b^2}{2}\int_0^\pi d\psi \times$$

$$\left[\left(2\lambda - \delta_0 + \frac{b^2\delta_1}{8}\right)\sin^2\psi - \frac{b^2\delta_1}{12}\sin^4\psi\right][1 - k\delta]$$

and from this equation

$$2\lambda - \delta_0 = -\frac{b^2\delta_1}{8} + \frac{L}{(\pi/4)\,\rho V^2 b^2[1 - k(\delta_b + {}^3/_{16}\,\delta_1 b^2)]} +$$

$$\frac{b^2\delta_1}{16}\,\frac{1 - k(\delta_b + {}^5/_{24}\,\delta_1 b^2)}{1 - k(\delta_b + {}^3/_{16}\,\delta_1 b^2)}$$

Introducing the mean lift coefficient C_{L_m} and the mean aspect ratio b/c_m one has:

$$\frac{L}{(\pi/4)\,\rho V^2 b} = \frac{C_{L_m}}{\pi/2}\frac{c_m}{b} \qquad (10)$$

Retaining only the first powers of the small quantities δ_b and δ_1 for a first approximation, this result is simplified to

$$2\lambda - \delta_0 = -\frac{b^2\delta}{16} + \frac{C_{L_m}}{\pi/2}\frac{c_m}{b}[1 + k(\delta_b + {}^3/_{16}\,\delta_1 b^2)]$$

and the following explicit expression for the circulation is obtained:

$$\Gamma = bV\sqrt{1 - (2x/b)^2}\times$$

$$\left[\frac{2C_{L_m}}{\pi}\frac{c_m}{b}(1 + k\{\delta_b + {}^3/_{16}\,\delta_1 b^2\}) - \frac{b^2\delta_1}{48}(1 - (4x/b)^2)\right]$$

and calling $(\Gamma)_{\delta=0} = \Gamma_0$

$$\Gamma = \Gamma_0 \times$$

$$\left[1 + k(\delta_b + {}^3/_{16}\,\delta_1 b^2) - \frac{\pi}{96}\frac{b^3\delta_1}{c_m C_{L_m}}(1 - (4x/b)^2)\right]$$

and for the lift distribution:

$$dL/dx = \Gamma(1 - k\delta) =$$

$$\Gamma[1 - k(\delta_b + (b^2/4)\delta_1\{1 - (2x/b)^2\})] \qquad (11)$$

To design such a wing of minimum total resistance it is necessary to use the relation

$$dL/dx = C_L(\rho/2)V^2 c$$

then to choose profiles and appropriate values of chords c and lift coefficients C_L. The corresponding angles of incidence α are then determined by the relation

$$C_L = 2\pi(1 - k\delta)(\alpha - i)$$

the angles α being measured from the angle for zero lift. Infinite aspect ratio characteristics of the airfoils must be used as the basis for this calculation.

Numerical Example

In order to form an idea about the relative magnitude of the deformation of the ideal elliptical lift distribution by the influence of the parasite drag the following probable numerical values are introduced.

$k = 7.5,\ \delta_0 = 0.031,\ \delta_b = \delta_0 - \delta_1(b^2/4) = 0.012,$
$C_{L_m} = 0.4,\ b/c_m = 6,\ k(\delta_b + {}^3/_{16}\,\delta_1 b^2 - \delta_0) = -0.0375,$

$$\frac{1}{3}\frac{b}{c_m}\frac{\pi}{2C_{L_m}} = 7.85,\ \delta_1\frac{b^2}{4}\left(k + \frac{1}{3}\frac{b}{c_m}\frac{\pi}{2C_{L_m}}\right) = 0.215$$

The lift distribution then becomes

$$dL/dx = 0.944\,\Gamma_0[1 + 0.228(2x/b)^2] \qquad (11a)$$

In this case the lift must be made larger toward the tips so as to have a fuller shape, and to compensate for this influence, the maximum of circulation must be 0.944 times as great as for the case without parasite drag.

This paper has treated only the isolated wing of minimum total resistance. A new problem arises if one wants to design a wing intersected by a hull body.

For pure induced resistance and the influence of a long cylindrical hull of circular cross-section Th. v. Kármán and J. Lennertz[6] have given a solution, which though rather more complicated than that for the simple wing would be worth extending to embrace the parasite resistance.

The theorem of Munk of the rigidly behaving vortex sheet (generalized and utilized here for an arbitrarily given distribution of parasite drag) has been extended by A. Betz[7] to the case of rotating wings (airscrew blades). His statement is that the helical vortex sheets left behind by the trailing edges of the blades induce an inflow angle change which for a minimum induced resistance (or minimum induced energy loss)

is the same as for a rigidly behaving helical plate. Introducing the reciprocal advance of the points of the blade axis $\omega r/V = s$ this theorem is given by the formula

$$i = \lambda s/(1 + s^2)$$

The method of proof of Fuchs applied to this problem proves the theorem in a remarkably simple way as correct to the same degree of approximation as the theorem of Munk and allows, as will be shown in another paper by the author, the analogous extension for an airscrew blade of minimum *total* energy loss with arbitrary distribution of parasite drag as simple as the one for the straight moving wing treated in the paper presented here.

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[4] Fuchs, R., *Theorie der Luftkräfte;* Aerodynamik, Vol. II, page 132. Julius Springer, Berlin, second edition, 1935.

[5] See reference 4, page 4.

[6] Lennertz, J., *Beitrag zur theoretischen Behandlung des gegenseitigen Einflusses von Tragfläche u. Rumpf;* Abhandlungen aus dem Aerodynamischen Institut a. d. Techn. Hochschule Aachen, Heft 8, page 3–30.

[7] Betz, A. (with an appendix by L. Prandtl), *Schraubenpropeller mit geringstem Energieverlust;* Nachr. d. Kgl. Gesellsch. d. Wiss. z. Göttingen. Math. Phys. Klasse, 1919.

Book Reviews

The Care and Maintenance of Aircraft; Bunhill Publications, Ltd., London, 1937; 194 pages, 5s.

This text concerns the airplane and engine from the maintenance viewpoint in synopsis form. While essentially written for the instruction of mechanics who desire ratings as "ground engineers" in different classifications, the book covers problems unquestionably encountered every day by the licensed mechanic, both airplane and engine. Because it covers the data briefly and does not rely greatly on illustrations, the text is primarily of value to the man with some knowledge and experience rather than to the novice. In using a very general outline, the author avoids the complications caused by the ever-changing nature of the structures and installations in airplanes. A mechanic who is familiar with his duties may secure from this book a basic foundation from which he might deviate to cover any specific work at hand.

The text should possibly include more diagrams, particularly control, lubrication, and fuel systems. More detailed attention might be given to inspection methods. The necessity of meticulously following the manufacturers' recommendations and instructions has not been emphasized sufficiently.

Although this publication should not be used as a complete manual for work projects, it is recommended to those mechanics who might be called upon to do work other than that ordinarily covered in their daily tasks with the thought that it might aid them in scheduling a complete method of attacking their problems.

Harold B. Fisher
George H. Lawton
Casey Jones School of Aeronautics

Deutscher Flugzeugbau; Handbuch der Luftfahrttechnik; edited by O. Hollbach; Fritz Knapp, Frankfurt A.M., Germany, 1939; 409 pages.

This is one of the most amazing handbooks that has been published in recent years. It contains so many data that are usually considered "secret" that it is equally surprising that it could come by mail from Germany under present conditions. For the convenience of English, French, Spanish, Italian, and Portugese readers the indexes and titles are repeated in these languages.

Of course, the descriptions, drawings, and data of German war planes are astonishing enough but when the sixty pages on aircraft armament and bombs are scanned it seems unbelievable that such material could be released at this time.

Fairly complete data with three-view drawings (a few cutaway drawings are included) are given for gliders, sailplanes, civil, military, training, as well as war planes. All types of aircraft engines are shown with sectional drawings and characteristics. The principal aircraft accessories, electrical equipment, flight, navigation, and meteorological instruments, as well as safety devices, are shown in detail. Construction materials, testing apparatus for aircraft, and aircraft engines are fully described. Photographic apparatus used with aircraft and a complete description of hangars and instruments for ground stations make the book encyclopedic in scope.

Each section was written by a specialist in the field. Critical comment on the contents is not necessary. The book will undoubtedly be difficult to obtain in the United States but will be available to members of the Institute at the library at Rockefeller Center.

An Introduction to Astronomical Navigation, by P. H. Legg; Chapman & Hall, Ltd., London, 1939; 102 pages, 10s. 6d.

It is generally understood that any individual hoping to become qualified successfully as a Celestial Navigator, must have an advanced knowledge of higher mathematics. This text, although quite thorough in its scope, does not particularly apply as an "Introduction" for anyone who does not have some good background in the basic requirements of Celestial Navigation.

The explanations and diagrams concern particularly spherical geometry and do not have sufficient conciliation with Celestial Navigation. This book could be improved considerably and made of universal value if the author were to take the point of view of the layman with little knowledge of higher mathematics and "tie in" the art of astronomical navigation. For example, "Chapter I, Paragraph 1" should start with the direct comparison of the sphere, as it is known in geometry, with the globe upon which we intend to navigate. This explanation would be greatly enhanced if the author would first explain a great circle as it would be employed in the actual astronomical navigation of a course on the globe.

Throughout this entire book, it is evident that considerable time and effort has been expended upon its development by the author but the true value would be more pronounced if this publication included more elementary data on general air navigation practices and procedure.

Kenneth B. Knox
Casey Jones School of Aeronautics

A Note on Short-Column Formulas

H. W. SIBERT

University of Cincinnati

Introduction

SHORT-COLUMN formulae used in airplane design are of the form

$$P_s/A = F_{co} - K(L'/\rho)^n \qquad (1)$$

in which P_s is the allowable short-column load; F_{co} is the column yield stress; $L' = L/\sqrt{c}$, where c is the fixity coefficient; ρ is the radius of gyration; and K is a constant of such a value that the short-column and Euler curves of allowable stress *versus* L'/ρ are tangent at the critical value of L'/ρ.

It is not easy to find from Eq. (1) the proper size tube for a given design load because both A and ρ are unknown. One way to overcome this difficulty is to construct grid-type nomograms similar to those given by Niles and Newell.* A second method is to construct curves of allowable column load *versus* L for both the short-column and Euler range.† Unfortunately, Niles and Newell exhibit only one such grid-type nomogram and Bulletin ANC-5 gives curves of allowable column load *versus* L for X-4130 steel only. Hence, designers might find use for a simpler formula for P_s than that given in Eq. (1).

A New Short-Column Formula

Such a formula can be obtained in terms of P_c and P_e, where P_c is the column load corresponding to the critical value of L'/ρ and P_e is the Euler load found from an extension of the Euler curve into the short-column range. This new formula is derived by equating the slopes and ordinates of the short-column and Euler curves. The final results are

$$P_s/P_c = 1 + 2/n - (2/n)(P_c/P_e)^{n/2} \qquad (2)$$

$$P_c = F_{co}A/(1 + 2/n) \qquad (3)$$

The only other formula needed is that for P_e, which is

$$P_e = \pi^2 EI/L'^2 \qquad (4)$$

The short-column and Euler ranges can also be determined from P_c and P_e. Since the Euler load decreases as L' increases (Eq. (4)), it is evident that

$$\left.\begin{aligned} &\text{Short-column range:} \quad P_e > P_c \\ &\text{Euler range:} \quad P_e < P_c \end{aligned}\right\} \qquad (5)$$

Design Procedure

The design procedure is as follows. Find I from Eq. (4) for the design load and length. Pick out a tube with this or a greater value of I from a table of tube properties, such as Table 8–1 of Bulletin ANC-5. For this tube find P_c from Eq. (3) and P_e from the relation

$$P_e = (\text{actual } I/\text{required } I) \times (\text{design load}) \qquad (6)$$

because P_e is proportional to I (Eq. (4)). If $P_e < P_c$, the tube is in the Euler range and P_e is the allowable load. If $P_e > P_c$, the tube is in the short-column range and P_s can be calculated from Eq. (2). If this value of P_s is less than the design load, a stronger tube must be chosen and new values of P_c, P_e and P_s calculated for it.

Example 1. Find lightest pin-ended ($c = 1$) round tube of 24ST if the length is 40 inches and the design load is 2000 pounds.

For 24ST, $n = 1$, $F_{co} = 50{,}000$, $\pi^2 E = 101{,}600{,}000$.
Required I (Eq. (4)) $= 2000 \times 40^2/101{,}600{,}000 = 0.0315$.
Try $1^3/_8 - 0.035$, $A = 0.1473$, $I = 0.03309$.
P_c (Eq. (3)) $= (50{,}000/3) \times 0.1473 = 2460$.
$P_e = (0.03309/0.0315) \times 2000 = 2100$.
Euler range because $P_e < P_c$.
Margin of safety $\doteq (2100 - 2000)/2000 = 0.05$.

Example 2. Find lightest pin-ended ($c = 1$) round tube of 24ST if length is 30 inches and design load is 3,000 pounds.

For 24ST, $n = 1$, $F_{co} = 50{,}000$, $\pi^2 E = 101{,}600{,}000$.
Required I (Eq. (4)) $= 3{,}000 \times 30^2/101{,}600{,}000 = 0.0266$.
Try $1^3/_8 - 0.035$, $A = 0.1473$, $I = 0.03309$.
P_c (Eq. (3)) $= (50{,}000/3) \times 0.1473 = 2460$.
$P_e = (0.03309/0.0266) \times 3000 = 3730$.
Short-column range because $P_e > P_c$.
P_s (Eq. (2)) $= 2460\,\{3 - 2\sqrt{(2460/3730)}\} = 3390$.
Margin of safety $= (3390 - 3000)/3000 = 0.13$.

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* Niles, Alfred S., and Newell, Joseph S., *Airplane Structures;* John Wiley and Sons, Inc., New York, 1938. See Fig. 10:13, Vol. 1.

† *Strength of Aircraft Elements;* Bulletin ANC-5; Army-Navy-Commerce Committee on Aircraft Requirements, January, 1938. See Fig. 4–5.

Second Annual Rotating-Wing Aircraft Meeting

Following is a résumé of the proceedings of the second annual Rotating-Wing Aircraft Meeting at The Franklin Institute in Philadelphia on November 30th, December 1st, and 2nd, 1939. It was sponsored by the Philadelphia Branch of the Institute. Over a hundred people attended and participated in interesting discussions at the technical sessions.

Capt. H. Frank Gregory of the U. S. Army Air Corps was chairman of the Thursday afternoon session, at which the following papers were presented.

"Army Experiences with Rotary Aircraft," by Lieut. E. S. Nichols, U.S. Army Air Corps. The author described experiments demonstrating the effective use of autogiros for: (1) direct wire telephone communication with ground crews; (2) use near the front lines where the small space required for take-off and landing makes their concealment relatively easy; (3) conducting troops on the march. It was concluded by the author that the autogiro is capable of defending itself against attacking airplanes from all sides except possibly from overhead attack. Their military use would be enhanced by improved roadability to facilitate their movement over the ground.

"Rotor Craft Drive Systems," by John M. Shuckers, Hilliard Clutch Corporation. The paper considered all possible types of rotor drives for an autogiro, starting from the premises that the system need not have a long total life since it is used only on take-offs and that it should transmit 50 hp. at 2000 r.p.m. The advantages and disadvantages of various systems were considered from the standpoint of two different paths of power transmission; a right angle drive to be carried horizontally backward from the engine for a distance of five feet to the rotor head extended, and a direct drive carried from the back of the motor directly to the rotor head. The following table gives the approximate weight and estimated efficiencies of the various systems.

Type	Weight, lbs.	Efficiency, percent
Hydraulic pump and motor	160	65
Electrical generator and motor	320	70
Mechanical clutches, belts, pulleys, and shafts (right angle drive)	80	85
(direct drive)	66	85
Mechanical clutches, chains, sprockets, and shafts (right angle drive)	75	95
(direct drive)	60	95
Mechanical clutches, gears, and shafts (right angle drive)	55	98
(direct drive)	45	98

Choosing the last system, for a sustained power type of rotorcraft (helicopter), the drive system would weigh between 90 and 110 lbs. and its efficiency would be 98 percent.

"New Parameter for Lifting Rotors," by Arthur M. Young, Paoli, Pennsylvania. The author described his experiments with rotors in which the tendency of the rotor to tip when its support was tipped was considered as the important factor determining whether or not the rotor was stable. The new parameter mentioned in the title was the "tipping factor," or the extent to which tipping of the rotor effects the angle of attack of a blade which is perpendicular to the plane in which the rotor is tipped. In the model tests the rotor with a tipping factor of zero (blades hinged at hub) was unstable while that with a tipping factor of unity (rotor mounted on a universal joint) was stable. The latter type was unstable in a wind. A rotor with a tipping factor of 0.5 was stable both in a wind and in still air.

"Roof Landing Problems," by Captain John M. Miller, Eastern Air Lines. The author began by describing the autogiro mail service from the roof of the Philadelphia Post Office to the Camden Airport, in which a 90 percent perfect schedule has been maintained during the first five months of the operations. He described the roof of the Post Office as unfavorable, largely because penthouses and sharp corners cause a great deal of turbulence. For profitable and safe operation of the service he recommended an autogiro with the following characteristics: (1) two motors; (2) pilot should be forward; (3) minimum vibration; (4) de-icing equipment; (5) suitable instruments both on the roof and in the autogiro. Recommendations relative to the roof were: (1) it should be at least 300 ft. square; (2) corners should be rounded and/or fitted with slots to reduce turbulence; (3) there should be hangar space below; (4) should have adequate lighting equipment (on the roof as well as on the high buildings in the vicinity); (5) provisions for a radio beam; (6) surrounding buildings should be studied relative to the turbulence they will produce; (7) the surface of the roof should be such that particles will not be picked up by the slipstream of the propeller.

On Thursday evening Igor Sikorsky gave an inspiring lecture on "Commercial and Military Uses of Rotating Wing Aircraft." He began by describing his experiments with helicopters, some thirty years ago. He next pointed out that the much talked of private "flivver" airplane field is lagging and predicted that rotating wing aircraft holds the key to its development. Its indifference to gusts and its maneuverability make it particularly adaptable. In Mr. Sikorsky's opinion the final answer will be capable of hovering, of vertical movement, and of rapid turning, though its forward speed will always be around 200 m.p.h. slower than the fastest fixed wing types. Among the military uses he included observation, scouting, and landing troops behind lines. Naval uses might include communication from ship to ship and ship to shore, observation, scouting, and life saving. Agnew E. Larsen was chairman of this evening session.

Prof. Alexander Klemin was chairman of the Friday morning session, at which the following papers were presented.

"Economic Significance to Passenger Traffic of Central-City Landings," by C. E. McCollum, Transcontinental and Western Air. The history of airport to city transportation services was recounted. At first this service was included in the ticket prices, but the downward revision of fares made it necessary to discontinue the practice. The author estimated that in 1938, 1,500,000 air passengers spent a total of 173 years travelling to and from airports. An air ferry system was recommended as the ultimate solution to the problem.

"Mechanical Design in Rotary Aircraft," by Joseph S. Pecker, Machine and Tool Designing Company. The author began by giving a chronological record of the evolution of the starter from the time the first autogiro was brought to this country in 1928, up to the present. He discussed by means of slides the detail design of starters and the losses in the systems. He maintained that the complete mechanical systems should include a starter, as well as a brake to check the blades in landing.

"Gyroplanes and Combination Types," by E. Burke Wilford, Pennsylvania Aircraft Syndicate. The various types of gyroplanes and combination types were compared, including (1) Cierva (hinged blade with tilting axis control), (2) Hafner (hinged

blade with feathering control), (3) Herrick (rigid rocking blade with rotor control), and (4) Wilford (semi-rigid blade with feathering control), on the basis of ruggedness, ease of balance, positiveness of control and reduction of control forces, stability in flight, and other factors. Each type was given a "figure of merit," based on the author's engineering judgment. Helicopters with single rotor, two coaxial rotors, and two side-by-side rotors, were treated in a similar manner. Finally, combination types of autogiro, helicopter, and airplane were described and were considered to be a promising type.

"Treatment of Performance Losses on Rotors with Center Cut-Outs," by Paul H. Stanley, Pitcairn Autogiro Company. The paper described efforts to eliminate the detrimental losses around the root-ends of the blades and at the hubs of autogiros. First attempts comprised fitting a lenticular covering of porous elastic fabric around the hub. This was found to be unsatisfactory. A second fairing, of sheet metal, covered with porous fabric, increased the top speed by 1 m.p.h. and cut down the rotational speed from 144 to 131.5 r.p.m. Analysis indicates that if the gross weight had been changed to bring the tip speed ratios of the faired and unfaired rotors to the same value at high speed, a greater advantage would have been shown for the faired rotor. The author recommends a fairing of rubberized fabric around the hub extending to the blade root-ends; the lenticular shape would be maintained by air bladders inside the fairing. The performance of blades running through the hub and those that end outboard of the hub and the effect of solidity were considered.

"Stress Analysis of Rotor Blades," by Hugh Mulvey, Kellett Autogiro Corporation. The procedure for stress analysis and the load factors given in the paper were based on theoretical considerations and upon the results of many strain gage tests in normal flight and in maneuvers. The following conditions were considered: (1) flapping of a blade on the ground; (2) starting conditions; (3) flight condition, including centrifugal tension, and the bending moments in the plane of the flapping, and in the plane of rotation; (4) fatigue loads. Formulas and safety factors used in the analysis were given.

H. J. E. Reid, Chief Engineer at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics, was chairman of the Friday afternoon session.

"Photographic Observations in Flight of the Stalling of Rotor Wings," by F. J. Bailey, Jr., of the National Advisory Committee for Aeronautics. The author described recent experiments at Langley Field in the wind tunnel and in flight. The wind tunnel experiments on l/d as a function of the tip speed ratio led to an optimum tip speed ratio of 0.35. The angles of attack of the blades were calculated for all points on the disc and compared with the stalled area determined in flight. A camera was mounted at the hub pointing along a blade; motion pictures of wool tufts attached to the blade were taken and analyzed. The stalled region was slightly larger than that calculated. The moving pictures were shown. It was concluded that the stalling angle of the blades of an autogiro should be greater than 15°.

"Rotor Controls" by Harris S. Campbell, Glenside, Pennsylvania. For attitude control the following two systems appear equivalent as far as aerodynamic characteristics and control loads are concerned. (a) Flapping pivots through center of rotation with pitch control. (b) Flapping pivots through center of rotation with tilting control fulcrums centered at plane of rotation. Tilting control has the following advantages: (a) Absence of torsional inertia blade loads in the controls. (b) In designs where pivot offsets do not create excessive control loads—simplicity of design for hub and control parts. (c) Adaptability for use with blade mountings on angular pivots to provide pitch change responsive to torque, lift effects, overspeeding, etc. (d) Freedom from vibrations arising from torsional motion of the blades. Among the advantages of feathering control systems are listed the following: (a) For use in heavy machines having considerable offset of the flapping pivots. (b) For control systems in which simultaneous pitch change is desired under operating conditions which cannot be readily reduced to simple automatic actuation. (c) For rotors which are intended to be used on different machines having widely different design characteristics. By modifying the control hook-up different characteristics may be imparted to the same rotor system.

"Frequency and Vibration Problems of Rotors," by Richard H. Prewitt and Robert A. Wagner, Kellett Autogiro Corporation. On the basis of a theoretical investigation the following conclusions were drawn: (1) With normal vertical pin locations, and without additional centering springs, the natural pendular frequency of the blade about the vertical pin is from $^1/_3$ to $^1/_8$ the rotor speed. (2) With additional specialized centering means, the natural pendular frequency of rotor blades may be made to vary with amplitude of oscillation. (3) The natural flapping frequency of a rotor blade with the flapping axis perpendicular to the blade, and located on the axis of rotation, neglecting damping, is equal to the rotor r.p.m. (3a) Moving the flapping axis outboard increases that natural frequency in a normal design roughly $2^1/_2$ percent. (3b) Average coning of the blade reduces the basic natural frequency in a normal design roughly 3 percent. (3c) Damping reduces the basic natural frequency approximately 15 percent with the flapping axis perpendicular to the blade. (3d) Cocking the horizontal hinge toward the leading edge of the blade has the effect of increasing the value of the damped natural frequency with increases in the angle of cocking. (4) The natural bending frequency in the plane of flapping depends so much upon the structure of the blade that no one value can be given for this term. The natural bending frequency in the plane of rotation for a plywood covered blade having a chord of 1 ft., a radius of 20 ft., and a 17 percent thickness ratio, at 200 r.p.m. of the rotor, is approximately $2^3/_4$ times the rotor speed.

"Notes on Autogiro Rotor Longitudinal Stability," by Prof. Alexander Klemin, Lieut. Victor R. Haugen, and Samuel B. Sherwin, New York University. To clear up the disagreement between experimenters with and designers of autogiros, the authors carried out a theoretical investigation and arrived at the following conclusions: (1) for a rotor with offset hinges, with moments referred to the center of the rotor, there is always a stalling moment; (2) the thrust moment may be positive or negative depending on the character of the flapping motion, but the inertia moment is so much greater that it determines the sign of the resultant moment; (3) the stalling moment increases with the tip speed ratio, and the center of pressure moves forward with increased angle of attack, *i.e.*, the rotor is inherently stable.

On Friday evening a successful and entertaining banquet was held at the Penn Athletic Club. A number of extemporaneous talks by prominent people in aviation was followed by a prepared address by Hon. E. P. Warner of the Civil Aeronautics Authority on the part of the C.A.A. in rotating-wing development.

On Saturday morning many of those attending the meeting witnessed landings and take-offs on the roof of the Philadelphia Post Office.

The Planning and Working Committee of the Philadelphia Branch, under the chairmanship of Agnew E. Larsen is to be congratulated on the planning and execution of a successful meeting.

A. M. KUETHE

Institute Notes

Eighth Annual Meeting Honors Night Dinner

Tentative programs for the Annual Meeting of the Institute in New York on January 24th, 25th, and 26th, 1940, have been mailed to members. Final programs will be sent out about January 15th.

The Honors Night Dinner will be held at the Hotel Biltmore. Mr. Donald W. Douglas will be presented with the Daniel Guggenheim Medal for 1939, and the Sylvanus Albert Reed, Lawrence Sperry, and Octave Chanute Awards will be presented. The newly elected Fellows and the American Honorary Fellow will receive their certificates and the next President of the Institute will be inaugurated. The guest speaker will be Hon. Robert H. Hinckley, Chairman of the Civil Aeronautics Authority.

Shell Intercollegiate Aviation Scholarships and Awards

Under the Sponsorship of the I.Ae.S.

The Shell Oil Company, convinced of the soundness of the Civilian Pilot Training Program, which has been established by the Civil Aeronautics Authority to provide for training approximately 10,000 pilots in 1940, and desiring to encourage the efficient training of the students who are undergoing instruction, and to advance their education along aviation lines, has established a fund of $15,000 to be used by the I.Ae.S. in establishing and administering scholarships and awards to be competed for by the students, the universities and colleges, and the flight schools participating in the program.

Recognizing the merits of a plan which is designed to augment the interest of new civilian pilots in aviation, and in order to focus additional attention upon the Civilian Pilot Training Program, the Institute has accepted the responsibility of administering the $15,000 fund and has created a Board of Awards which will select the successful contestants.

The method of conducting the contest leading to the selection of the recipients of the awards is briefly as follows. On or before June 15th, 1940, the National Board of Judges will select, on the basis of recommendations and records, the seven outstanding student pilots in each of the seven C.A.A. regions. These candidates will meet at a designated time and place in each region for the Semi-Final Tests. The winners of each of these regional tests will compete in the Final Tests on a designated date in Washington, D.C.

The awards are as follows: three Shell Aviation Scholarships of $1000, $750, and $500, respectively, to be awarded to the three outstanding pilots developed during the year through the Civilian Pilot Training Program; the Shell Intercollegiate Aviation Trophy, to be awarded to the flight school which trained the students of the winning college; each of the seven flight instructors of the seven pilots who compete in the finals will be awarded $50; each of the seven regional flight contest winners will be awarded a suitably engraved aviation wrist watch; each of the forty-nine contestants selected to compete in the regional elimination contest will receive a parchment certificate.

The Board of Awards comprises the Presidents of the Aeronautical Chamber of Commerce, the Air Transport Association of America, the National Aeronautic Association, and the National Association of State Aviation Officials, respectively, the Executive Director of the Association of American Colleges, and the Executive Vice-President of the I.Ae.S. The men holding the above offices for the year 1940 will constitute the Board of Awards. The presentation of the awards will be made in Washington, D.C., about July 1, 1940.

Gifts to the Institute

The Institute is greatly indebted to the Royal Aeronautical Society for a gift of ninety-one copies of back numbers of the Journal of the Royal Aeronautical Society, all of which appeared before 1921. The Institute library has bound volumes of the Journal from 1921 to date. With this gift eighteen complete volumes will be added and as a search is being made for missing issues it is hoped that the Institute will soon have a complete set of these important volumes, which commenced in 1868. The Institute appreciates greatly the spirit which prompted the Royal Aeronautical Society to present these valuable issues. It is another indication of the cordial and cooperative spirit which exists between the two societies.

The following books have been received for the library: *Aircraft Handbook*, by Colvin and Colvin, from Charles Colvin; *Deutsche Flugzeugbau; Handbuch der Luftfahrttechnik*, by Dipl.-Ing. O. Hollbach, 1939, from Otto Merkel; *Freedom of Passage for International Air Services*, by L. H. Slotemaker, from Dr. C. A. Kofoid; *British Standard Exporter, 1920–21*, and *Avions Allemand, 1915–16*, by Jean Lagorgette, from Comdr. Ralph S. Barnaby; *National Encyclopedia*, 10 vols., from Thomas H. Bech; *Canada's Fighting Airmen*, by Lieut. Colonel George A. Drew, from the MacLean Publishing Co.

A model of the Wilford Gyroplane, the gift of E. Burke Wilford, has been added to the Institute collection which is on exhibit at the N. Y. Museum of Science and Industry.

Mrs. Frank Hawks has given the Institute a trophy which was presented to Frank Hawks. It was made from the propeller of his famous "Mystery Ship."

Mrs. H. E. Warren has given a collection of clippings which are principally about soaring and the work of her late husband Warren J. Eaton.

Captain William J. Tate of Kitty Hawk, who was the guest speaker at the luncheon preceding the Wright Brothers Lecture on December 16th, presented the Institute with pieces of wood and fabric from the first Wright Brothers glider used at Kitty Hawk in 1900. He also gave a piece of the original Wright hangar at Kitty Hawk, which may be regarded as the first airplane hangar in the world.

Personnel Opportunities

The Personnel Bureau serves individual members, as well as organizations seeking to employ aeronautical specialists. Any member or organization may have notices listed without charge.

Available

Lecturer in Aeronautics (U.S. citizen), just returned from overseas appointment with foreign technical college, seeks similar employment in the United States. High school and youth movement considered. Subjects: Aerodynamics; mechanics of flight; navigation; shop practice; model airplanes, their design and construction; and related subjects. Address Box 96, Institute of the Aeronautical Sciences.

Civil Service Examinations

The U.S. Civil Service Commission has announced open competitive examinations for Special Agent ($3800 per year) and Assistant Special Agent ($3200 per year) for duty with the Civil Aeronautics Authority. The duties of the positions are largely in connection with the enforcement of certain sections of the Civil Aeronautics Act of 1938. Competitors will be initially rated on the basis of education and experience. If conditions permit, a subsequent oral examination will be required of selected

applicants. Complete information on the qualifications, duties, etc., is available at most post offices. Applications must be on file with the U.S. Civil Service Commission in Washington, D. C., not later than January 23, 1940, if sent from the East or Middle West; applications from western states must be on file not later than January 26, 1940.

Branches

Los Angeles. Prof. Clark B. Millikan repeated the Third Wright Brothers Lecture at a meeting of the Branch on December 21st. Following the lecture, prepared discussions by W. Bailey Oswald, E. J. Horkey, and Phillip Colman, aerodynamicists at the Douglas, North American, and Lockheed companies, respectively, were presented. The technical program was preceded by a dinner. The meeting was attended by 110 members.

Student Branches

Polytechnic Institute of Brooklyn. At a meeting on November 9th, Robert Miles spoke on "Duramold as a Material for Airplane Fuselages." Following this, Robert Crown led an interesting discussion on "Boomerangs." On November 30th Mr. Alexander Dawydoff, Gliding and Soaring Editor of "Air Trails" gave an interesting lecture on the history and technique of piloting the various types of motorless aircraft. Technicolor motion pictures, taken at the Elmira meet and at Hicksville, were shown.

Catholic University of America. On November 15th two motion pictures, entitled "Some Effects of Nozzle Design on Combustion in a High Speed Compression-Ignition Engine" and "A Study of Air Flow in an Engine Cylinder," respectively, were shown. The films were loaned by the N.A.C.A. A discussion followed the presentation. At the same meeting the following officers were elected: Charles Kaman, Chairman; Charles Chaney, Vice-Chairman; Joseph Ellis, Secretary and Treasurer.

University of Detroit. At the November meeting, Lieut. Caldwell, Flight Commander of the First Pursuit Group stationed at Selfrige Field, spoke on his early training experiences and outlined the training that a C.A.A. student might expect. The second feature on the program was a sound film "Aluminum Fabricating Processes," showing the various methods for fabricating aluminum.

Massachusetts Institute of Technology. The second meeting of the school year was held on November 27th. A sound film showing the building of the Consolidated PBY was presented through the courtesy of the Consolidated Aircraft Corporation. About 250 members and friends attended the meeting.

University of Michigan. At a meeting on November 19th, Prof. E. T. Vincent gave an interesting talk on "Aviation Fuels." During the discussion following the lecture the subject was broadened to include automobile fuels. The meeting was attended by about 50 members and friends.

Notre Dame University. On December 8th Robert S. Eikenberry spoke to the members of the Branch on "Aspects of Gliding," covering the history and technique of altitude and cross-country gliding. At the conclusion of his talk Mr. Eikenberry showed the motion picture "Plane Sailing," furnished by the Soaring Society of America, and a number of slides made from photographs taken at the Elmira meet. There was a discussion of the competition between students for the best paper presented at branch meetings. The Department of Aeronautical Engineering has offered cash prizes for the best papers.

Tri-State College. About thirty students attended a meeting on November 20th at which Prof. Edward Rose spoke on "Aviation Fuels." An interesting discussion followed the presentation.

Changes in Membership

The following changes in the membership of the Institute have occurred since the publication of the previous issue of the Journal:

Elected to Member Grade

Adams, Harold Lamont, B.S. in Ae.E.; M.I.Ae.S.; Engineer in charge Structural Testing, Boeing Aircraft Co.

Clark, James Montgomery, M.I.Ae.S.; Director, Patent Research Div., Manufacturers Aircraft Association.

Haberlin, John Frank, M.I.Ae.S.; Asst. Project Engineer, Boeing Aircraft Co.

Paxton, Charles Norman, A.B. in M.E.; M.I.Ae.S.; Assoc. Prof., Mech. Engineering, Univ. Oklahoma.

Lucas, Philip Dearborn, M.I.Ae.S.; Supervisor, Aircraft Operations, Bell Telephone Laboratories, Inc.

Shepley, Philip, LL.B.; M.I.Ae.S.; Sales Engineer, Export Sales Div., Curtiss-Wright Corp.

Stevens, Herbert Lawrence, B.A.; M.I.Ae.S.; F.R.Ae.S.; Deputy Chief Air Representative, British Supply Board in U.S.A. and Canada.

Valentine, Edwin Floyd, B.S. in M.E.; M.I.Ae.S.; Jr. Aero. Engineer, N.A.C.A.

Elected to Technical Member Grade

Bratsch, Chester Henry, Layout Draftsman, Vultee Aircraft Div., Aviation Mfg. Corp.

Forman, Edward Seymour, Jet Propulsion Research, Calif. Inst. of Technology.

O'Connor, John Brown, B.S. in C.E.; Sales Engineer, Shakeproof Lock Washer Co.

Philipp, Paul Alois, Draftsman, Lockheed Aircraft Corp.

Takasugi, Kingo, Stress Analyst, Harlow Aircraft Co.

Transferred from Member to Associate Fellow Grade

Capt. Harry G. Armstrong, Director, Aero Medical Research Lab., Materiel Div., U.S. Army Air Corps; Kenneth Campbell, Project Engineer, Wright Aeronautical Corp.; F. A. Louden, Aero. Engineer, Aerodynamics Sec., Bureau of Aeronautics, Navy Dept.

Transferred from Technical Member to Member Grade

Michael J. Phillips, Project Engineer, Aircraft Hydraulic Equipt., Pump Engineering Service Corp.

Transferred from Student Member to Technical Member Grade

Morton Alperin, Jr. Engineer, U.S. Army Air Corps; Harold R. Beemer, Stress Analyst, Vultee Aircraft Div., Aviation Mfg. Corp.; William M. Benson, Flight Research Engineer, El Segundo Div., Douglas Aircraft Co.; Daniel S. Birnbaum, Jr. Detail Assembler, Vega Airplane Co.; Francis X. Bradley, Jr., Flying Cadet, U.S. Army Air Corps; Emerson C. Briggs, Inspector, Glenn L. Martin Co.; Chester W. Brooks, Jr. Detailer, Lockheed Aircraft Corp.; Gerald F. Brott, Engineer, Boeing Aircraft Co.; Abraham J. Bye, Planner, Fairchild Aircraft Ltd., Canada; Michael A. Caruba, Engineer, Brewster Aeronautical Corp.; Felix Chardon, Engineer, Glenn L. Martin Co.; George H. Compter, Aero. Engineer, Brewster Aeronautical Corp.; James E. Crawford, Draftsman, Curtiss Aeroplane Div., Curtiss-Wright Corp.; Frank M. Crosby, Jr. Engineer, Allison Engineering Co.; Robert P. Dietz, Production Engineer, Bell Aircraft Corp.; Harold W. Donald, Tester, Link Trainers; Homer W. Dotts, Layout Engineer, Curtiss Aeroplane Div., Curtiss-Wright Corp.; Donald W. Douglas, Jr., Draftsman, Douglas Aircraft Co.; George C. Durling, Jr., Draftsman, Glenn L. Martin Co.; C. Kent Englund, Instructor, Curtiss-Wright Technical Institute; Robert H. Fagan, Research Fellow, Georgia Engineering Experiment Station, Georgia School of Technology; Walter J. Fancher,

Jr., Jr. Detail Draftsman, Lockheed Aircraft Corp.; Charles L. Fay, Jr. Engineer, Research Div., United Aircraft Corp.; Andrew Fejer; Ned Fuller, Jr., Engineer, Stinson Aircraft Div., Aviation Mfg. Corp.; Arthur G. Gross, Stress Group, El Segundo Div., Douglas Aircraft Co.; Alexander Goldberg, Detail Draftsman, Lockheed Aircraft Corp.; Richard H. Guthrie, Engineering Dept., Canadian Car & Foundry Co. Ltd., Canada; Charles W. Guy, Jr. Layout Draftsman, Lockheed Aircraft Corp.; Frederick D. Knoblock, Asst. General Mgr., Thornton Tandem Co.; Walter Krzymowski, Aero. Engineer, Glenn L. Martin Co.; Wesley A. Kuhrt, Research Assistant, Mass. Inst. of Technology; J. E. Lampman, Draftsman, Vultee Aircraft Div., Aviation Mfg. Corp.; George D. Linklater, Meteorologist, Eastern Air Lines; John M. Logan, Engineer, Lord Manufacturing Co.; John E. McElroy, Jr. Test Engineer, Wright Aeronautical Corp.; Charles D. Pease, Radio Operator, United Air Lines Transport Corp.; Charles W. Penry, Engineering Dept., Braniff Airways, Inc.; Albert J. Perry, Jr., Draftsman, Glenn L. Martin Co.; Elwyn H. Peters, Draftsman, Curtiss Aeroplane Div., Curtiss-Wright Corp.; Paul J. Powers, Jr., Research Engineer, Scintilla Magneto Co.; Edouard M. Propper, Stress Analyst, Consolidated Aircraft Corp.; Borge A. Rasmussen, Draftsman, El Segundo Div, Douglas Aircraft Co.; John D. Rittweger, Draftsman, Vega Airplane Co.; John H. Russell, Wind Tunnel Model Designer, Boeing Aircraft Co.; Gerald V. Rutkoskie, Engineer, Douglas Aircraft Co.; George Van Schliestett, Asst. Engineer, Bureau of Aeronautics, Navy Department; Ralph H. Shick, Aero. Engineer, Vultee Aircraft Div., Aviation Mfg. Corp.; Alfred R. Siegrist, Draftsman, El Segundo Div., Douglas Aircraft Co.; Roderick N. Smith, Sr. Detailer, Lockheed Aircraft Corp.; Leland K. Smull, Jr. Aero. Engineer, N.A.C.A.; John D. Stephens; Vincent C. Trimarchi, Instructor, Rensselaer Polytechnic Institute; Vincent S. Ward, Chemist, Adirondack Steel Co.

Necrology

ANTHONY H. G. FOKKER

Anthony H. G. Fokker, a Fellow and Founder Member of the Institute, died in New York on December 23, 1939, of pneumococcus meningitis. Lester D. Gardner, Executive Vice-President, represented the Institute at the funeral as honorary pallbearer.

Mr. Fokker was born at Kediri, Java, in the Dutch West Indies, on April 6, 1890. His family returned to Haarlem, Holland, where he attended school and where his ashes will be buried.

Before he had ever seen an airplane in flight he started to build his first machine, a monoplane, in which he taught himself to fly in 1910. He took his plane to Russia in 1912 and entered the international military competition in Moscow. When the war began in 1914 he offered his designs to many belligerent countries but only Germany accepted his proposals. He organized a factory in Germany and sub-contracted with 35 others. Eight thousand Fokker aircraft were built for war service. He developed a synchronized machine gun to fire through propellers. Over 42,000 of these synchronizers were made in Germany.

After the Armistice, in 1919, Mr. Fokker returned to Holland with a large fortune, a great amount of manufacturing equipment and many new designs, and started an airplane factory in Amsterdam which is still manufacturing both military and commercial types of airplanes.

Coming to the United States in 1922 he started the Atlantic Aircraft Company which was later absorbed by General Motors and renamed the Fokker Aircraft Company, with the inventor as its consulting engineer. In 1930 he sold his interest in the company and its name was changed to General Aviation Corporation. Foreseeing the great possibilities of the Douglas air transports Mr. Fokker secured the manufacturing rights and exclusive sales representation for these types in Europe. He sold nearly one hundred of these airplanes to foreign airlines. He also was interested financially in Air Cruisers.

Many of his airplanes made world records and were used on famous flights. Sir Charles Kingsford Smith flew his Fokker "Southern Cross" from Ireland to Newfoundland across the Pacific Ocean. Rear Admiral Richard E. Byrd flew across the Atlantic in a Fokker airplane and, with the late Floyd Bennett, in 1926 flew over the North Pole. Kelly and Macready, the Air Corps pilots, made the first non-stop transcontinental flight, Maitland and Hegenberger flew from San Francisco to Hawaii, and Amelia Earhart flew across the Atlantic, all using Fokker designed airplanes.

Mr. Fokker became an American citizen and during the past few years was also interested in the design and construction of streamlined motor boats.

Book Reviews

Physical and Dynamical Meteorology, by DAVID BRUNT; The Macmillan Company, New York, 1939; 428 pages, $6.75.

Readers of the first edition of Professor Brunt's book are quite aware of its extensive scope. That such a tremendous amount of material could be compressed into one volume of slightly over 400 pages is in itself no small accomplishment. In his second edition, Brunt has made a number of valuable additions, and at the same time has omitted a few portions of the original which seem to be superfluous in the light of modern meteorology. While it is obvious that it is a difficult task to arrange the many theories which are discussed, all of which being more or less interdependent, their organization in the first edition has been open to a certain amount of criticism. It is felt that Brunt has made definite improvements in the second edition in regard to the arrangement of his material.

The aim of this book, as the author states, is to provide a textbook of physical meteorology suitable for post-graduate students. It is true that certain portions, notably the sections devoted to the study of turbulence, will offer some difficulty to the readers who are not mathematically inclined. In general, however, it is believed that most of the mathematical manipulations will not be unduly complicated to the average student of meteorology. In regard to certain criticisms of his first edition with respect to the large number of equations discussed, Brunt takes the view that ". . . meteorology should aim at being a metric science whenever possible, and that no physical theory can be regarded as wholly satisfactory which cannot be expressed in mathematical form." The reviewer firmly agrees with this point of view; at the same time, however, it is felt that the phenomena of the science of meteorology, with its many complicating variables, are particularly in need of clear, verbal explanations, which should go hand in hand with the mathematical equations. It is worthy of note that Brunt has struck a happy compromise between the two methods of attack, verbal and mathematical, and has produced a book which will be understandable, in general, to all students of meteorology.

The author has devoted a considerable portion of his book to a discussion of thermodynamics as applied to the atmosphere. In the new edition he has included further considerations as to atmospheric stability and instability, and has gone into detail in

regard to the wet bulb and equivalent potential temperatures. Although Brunt's treatments concern themselves mostly with the wet bulb potential temperature, the results obtained are obviously identical with those which would occur by use of the equivalent potential temperature, since the former is a one-valued function of the latter. The second edition also contains a section devoted to the Rossby diagram, and points out the value of this chart as a means of identifying air masses.

In the second edition, a qualitative discussion of the condensation of water vapor on nuclei has been added. This section, which contains reference to the investigations of many workers in the field, briefly describes Bergeron's theory in regard to the formation of water droplets on ice crystals. The recent work of Findeisen is also discussed, which, among other things, offers a confirmation of Bergeron's views.

The treatment of the subject of radiation is quite complete, taking up approximately fifty pages. To this comprehensive section Brunt has added several new items, including references to the recent investigations of Elsasser and of Dennison pertaining to the effect on the lines of the water-vapor spectrum, of variations in temperature and total and partial pressure.

Two chapters of the book are concerned with the study of turbulence, the results of investigations of Prandtl, von Kármán, Taylor, Richardson, and others. In this section Brunt discusses problems such as the variation of wind with height, evaporation, air flow along and across isobars, and the vertical transfer of heat by turbulence. An important addition to the discussion on turbulence which appears in the new edition is the recent work of Rossby and Montgomery, who take into account the effect of stability upon the vertical variation of wind.

In regard to the polar front theory, one chapter devoted to this subject has been included. This should be of practical interest. The second edition contains the results of some new investigations of J. Bjerknes pertaining to the structure of depressions at high levels, and the relationship between waves in the tropopause and polar front perturbations. It should be emphasized here that this book is not a synoptic meteorology textbook; rather, it is a clear explanation of the dynamic and physical aspects of the frontal theory.

The writer has mentioned only a few of the new features, appearing in the second edition, which appear to him to be most significant. It is unfortunate that it does not include a discussion of the theory of isentropic analysis, the use of which has become a matter of routine among American meteorologists; it is only within the last year or two, however, that the great value of this type of analysis has been proved, and the scarcity of literature on the subject at the time the book was written may be an explanation for its omission. Nevertheless, the important additions which have been included in the second edition to bring it up to date, combined with the clear, basic explanations which have been carried over from the first edition, cause the new book to be outstanding as a textbook for physical and dynamical meteorologists, and a valuable reference book for all students of meteorology.

R. D. FLETCHER
Massachusetts Institute of Technology

Airplane Design Manual, by FREDERICK K. TEICHMANN; Pitman Publishing Corp., New York, 1939; 345 pages, $4.50.

The *Airplane Design Manual* should prove a boon to pupil and instructor in providing information and methods of attack. Aerodynamic and structural theory are very wisely left to books written specifically to cover those subjects in detail.

In general, the book covers, first, procedure in design, weight estimate, three view, and the balance diagram. Sample tables and figures are given to show just what procedure and form should be used in the preliminary design Next, several chapters are given on arrangement of pilot's cockpit, instrument board, passenger cabin, heating and ventilation system, soundproofing methods, and power plant installation. A number of figures are given here to illustrate the above arrangements as well as drawings giving actual measurements of seats, pilot's control system, lavatory equipment, etc. The appendix at the back of the book also supplements these pages, giving actual measurements of many parts so necessary for practical layout of an airplane three view. The latter part of the book is then devoted to the more basic airplane parts such as fuselage, landing gear, wing, and control surfaces. Discussions and diagrams of various shapes, structures, etc., are here included.

Chapters XV and XVI are devoted to preliminary calculations of stability and performance. It is probably a matter of individual opinion as to whether these should have been left to texts specializing in aerodynamics as the author apparently intended to do when he set out to write the manual.

The book has indeed filled a definite need in the teaching of airplane design, and it is recommended as a text for the student beginning that work.

A. M. SCHWARTZ
Georgia School of Technology

Practical Air Navigation and the Use of the Aeronautical Charts of the U.S. Coast and Geodetic Survey, by THOBURN C. LYON; U.S. Govt. Print. Off., Washington, 1939; 199 pages, $0.65.

It was this writer's pleasure to review the first edition of this book for the Journal of the Aeronautical Sciences. At that time Mr. Lyon was highly complimented for his excellent work. The position this book now holds in the aviation industry fulfills that original opinion.

With the improvements and additions in this revised edition, it becomes, to a greater extent, a more valuable book and almost an absolute necessity to those engaged in flying.

The chapter on "Dead Reckoning," together with a little applied practical work, should make any layman a navigator of sufficient ability to fly his aircraft from point to point with the definite assurance of being "on course" throughout his flight.

The chapter on "Celestial Navigation" gives an excellent picture of this type of navigation but, needless to say, a high type of mathematical background is required and more advanced practical experience necessary before an individual may attempt this type of navigation.

Meteorology is completely covered. With the aid of weather maps and radio bulletins, the layman can become a good enough forecaster to avail himself of the best flying conditions.

The author of this book deserves the thanks of the entire flying personnel in the aviation industry for his excellent portrayal of this complicated subject. It is written in simple language, is easily understandable, and is fast becoming the leading publication on the subject.

KENNETH B. KNOX
Casey Jones School of Aeronautics

Ahriman: A Study of Air Bombardment, by OLIVER LYMAN SPAULDING; World Peace Foundation, Boston, 1939; 143 pages, $1.00.

The World Peace Foundation operates on the policy that the actual facts concerning international relations constitute the best possible arguments for improved international understanding. Its activities aim to make these facts available in a clear and interesting form.

The subject of bombing from the air has been treated in many articles and books but it is difficult to find any book which deals exclusively with this limited field. General Spaulding, after a distinguished career in the U.S. Army, became chief of the historical section of the Army War College, where he had access to

sources of material which he used to excellent purpose in this study.

After a clear statement of the general principles of bombardment as practiced in military and naval operations he gives a concise summary of the doctrine of General Douhet and his plan for a mass airplane attack, by an Eastern power, on France. With this as a basis of discussion he analyzes the plan and reviews criticisms of the procedure by General Golovine and others.

Reviewing the experiences of air bombardment in the World War, Spain, Ethiopia, China, and Iraq, he shows that at no time have the extensive operations foreseen by the Italian strategist been tried. The cost of air activity on such a large scale is considered and the possible results evaluated in the light of experience up to now.

The author considers possible preventive action by international agreement and reprints the general rules of air warfare as drafted by various commissions.

Although the book is only a short summary of the present state of aerial bombing, those who wish to explore the field further are provided with an excellent bibliography.

A.R.P., by J. B. S. HALDANE; Victor Gollancz, Ltd., 1939; 293 pages.

No book on air raid precautions has caused more comment than this critical discussion by a scientist of great reputation. During the War Dr. Haldane was an expert on gas masks and defense, and has been a continuous observer of air warfare. He spent three months in Spain studying bombing from the air and acted as a member of the committee of the Labour Party on Air Raid Protection. He frankly states that he hated to write the book but that he felt that it was his duty to stimulate government activity.

Sir Samuel Hoare, the head of the Home Office, has made a great effort to organize the British public into a manageable unit that would function well in time of trouble. Wing Commander Hodsall, formerly of the R.A.F. has done superhuman work in preparing the country for eventualities. But part of the public has remained apathetic. Its attitude is typified by the quotation: "The whole thing is so beastly that we will have nothing to do with it. If we are going to have to burrow underground, life won't be worth living."

Dr. Haldane boxes the compass in his observations. He gives the history of air bombing, describes the early precautionary measures and then analyzes the plans now being made to protect English citizens. He gives agonizing eye-witness stories of what he saw in Spain and then treats the whole subject from a political standpoint, which after all is one of the vital problems.

A Ministry that would go to war without doing all it could to inform the public of and protect it from the great dangers of air warfare would not last overnight. How much of the A.R.P. effort is predicated on this theory would be unfair to judge. Americans at a safe distance and with no need for air raid precautions can only read such books with astonishment.

World in Arms, by R. ERNEST DUPUY; The Military Service Publishing Company, Harrisburg, Pennsylvania, 1939; 103 pages, $2.00.

It would be difficult to find a more timely book than this study in military geography. As the war operations proceed it becomes increasingly difficult to follow the progress with ordinary atlases. Major Dupuy evidently sensed the need for such a book well in advance of the outbreak of war, since the foreword is dated August 1st.

Condensed summaries of the size and components of the military, naval, and air strengths of practically every country in the world are supplemented by specially drawn maps, making it easy to understand military and aerial operations.

Our readers will be particularly interested in the maps, as the routes to the leading cities from the nearest airports of adjacent countries are shown. Using a speed of 250 miles per hour as a standard, the time to fly each route is given.

Of course the strengths of the air forces of all countries are a most debatable question. Each expert seems to have his own ideas of numbers, classifications, and reserves. For the numbers used in this book the least that can be said is that they are conservative. Undoubtedly they are the result of investigation of sources that may be regarded as well informed, but conditions are changing so rapidly that they may better be regarded as a base line from which the present forces can be calculated by reference to the productive capacity of each country.

As an example, Major Dupuy gives Germany 96 heavy bomber squadrons with 1000 airplanes, 30 light bomber squadrons with 360 airplanes, 108 fighter squadrons with 1296 airplanes, and 30 reconnaissance squadrons with 400 airplanes, or a total first line operating strength of 3056 airplanes. To these he adds an equal number of first-line reserves less than three years old and 2500 airplanes of obsolescent types, bringing the total to 8612 airplanes, to be flown by 10,000 military pilots and 55,000 airmen in other ranks.

To Great Britain he gives, using the same breakdown, 7100 airplanes, to Italy 3960, to France 3700, to Russia 5550, and to the United States, for the Army and Navy combined, 2400 military airplanes with 1200 additional training and cargo aircraft. Whatever opinions one may have as to the accuracy of these estimates they are at least interesting and give, with the military and naval figures, a general idea of the relative strengths of respective war forces.

The book will be one of the most useful handbooks with which to follow the progress of the present war.

Your Career in Aviation, by CHARLES S. MATTOON; Foster and Stewart, Buffalo, New York, 1939; 146 pages, $1.50.

At a time when there is such a demand for men in the aeronautical industry, any book which informs young men of the requirements for various positions is helpful. Mr. Mattoon has written a practical book based on his wide experience as Personnel Director for the Curtiss Aeroplane Division of the Curtiss-Wright Corporation. In it he tells how to apply for a job and then gives in detail the requirements for each type of work. He differentiates between work in factories, with airlines, and at air fields. Any young man who is considering seeking employment in aviation will save himself and personnel managers much unnecessary explanation by reading this book before he applies for work. The book will also be useful to those whose advice is sought by young men interested in a career in aviation.

Chemistry of Synthetic Resins, by CARLETON ELLIS; Reinhold Publishing Corporation, New York, 1935; 1620 pages, $19.50.

The emergence of synthetic resins as an important technological advance is one of the wonders of our age. The horizon seems almost unlimited and their potential value in aeronautics is just beginning to be appreciated. The present work, appearing in 1935, does not treat specifically some of the newer compounds and applications, but its fundamental approach to the subject is as valid today as it was four years ago.

The chemistry, synthesis, production, and chemical properties of all types of synthetic resins are treated in detail. Physical properties of the various products are not given.

Written from the standpoint of the chemist this work collects the data from literally thousands of references. This compilation alone makes it indispensable for those charged with the synthesis, production, and use of plastics. It is completely indexed and the illustrations are excellent.

Aeronautical Reviews

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps

Aerodynamics

Aviation Experimental Center, Guidonia. Research at this Italian aeronautical research center is divided into the following five divisions: the material division comprising the sections of aerodynamics and hydrodynamics, development of engines, and test section for both models and complete machines; instrument division with a flying instrument section and photography section; chemico-technological division with a technological section, physico-chemical section, fuel-study section, and inorganic chemistry laboratories; radio-electrical division which studies radio in relation to aviation; and experimental division which serves as a coordinating organization between the others and has general direction of experiments. The aerodynamic and hydrodynamic sections, engine laboratory, flying instrument section, optico-photographic section, technological section, and other laboratories are briefly described and reference is made to the physico-chemical and fuel-study sections. *Engineer*, October 20, 1939, pages 393–395, 3 illus.

Experimental Research in the Guidonia Supersonic Wind Tunnel. Lt. A. Ferri. Problems and tests made in the development of a series of transformer jets to create the requisite speeds in the test chamber, of a balance, and of the striometric and interferometric apparatus are discussed. Reasons leading to the adoption of the present scheme, and reasons derived from experiments with the temporary plant are presented. Systematic experiments in the sonic field with the makeshift equipment are also described.

It was considered that to substitute for strata of infinite inertia around the current (as in the case of flow surrounded by rigid walls) strata of no inertia at all (as in the case of free flow) gives divergences less than real ones, especially if dimensions of the test wing are reduced to the minimum possible. Therefore two tunnels capable of creating a jet with free flow, for measuring forces and determining pressures, respectively, were specially constructed.

Test results indicate that at low speeds, until the shock wave appears, behavior of pressures is in agreement with the Prandtl-Glauert theory. As soon as, through the low pressure, the speed of sound is surpassed, subsequent recompression takes place by means of a shock wave which noticeably affects the behavior of pressure. After the shock the low pressure, having slowly decreased for a while, drops rapidly. As speed goes on increasing, the shock tends to move backward, the low pressure in front shrinks still more, and a slight low pressure begins to form on the under surface near the leading edge. With still further increase in speed, supersonic speed occurs after the shock.

The phenomenon changes because after the first shock there is a subsequent expansion, leading to a marked increase in speed. As Mach Number increases, low pressure near the leading edge diminishes, while low pressure on the under surface increases proportionately. At high Mach Number, when the second wave appears, it also grows in the vicinity of the trailing edge. Center of pressure of the profile moves backward, and pitching moment of the wing relative to the leading edge increases with increase in speed. Translated from "Jahrbuch 1938 der Deutschen Luftfahrtforschung." *Jour. Royal Aeronautical Soc.*, October, 1939, pages 803–839, 29 illus.

Photographic Study of Fluid Flow between Banks of Tubes. R. P. Wallis. Experimental work carried out by the Civil Engineering Department of Imperial College, London, has shown that the Ahlborn method can be used for the study of flow in nests of tubes. Conditions for obtaining useful photographs are: a blackcloth background covered with glass; an illumination of about 400 lumens/sq.ft. for 18/10 deg. DIN. plates, and a camera aperture of f.16; camera lens aperture to be varied inversely as the square root of the speed in that part of the flow of chief interest, and no account to be taken of shutter speed; shutter speed to be d/8 V; sufficient aluminum dust to disclose the whole flow pattern readily; image on the plate to be of suitable size for printing in an enlarger; water speed not greater than 5 cm./sec. or less than that due to possible thermal circulations. Results with various arrangements and shapes of tubes are illustrated. Institution of Mechanical Engineers paper. *Engineering*, October 13, 1939, pages 423–426, 15 illus.

Some Modern Methods of Research in the Problems of Flight. G. W. Lewis. Paper previously abstracted from preprint. *Jour. Royal Aeronautical Soc.*, October, 1939, pages 771–800, 21 illus.

The Propagation of Shock Waves in Air—I. L. Thompson and N. Riffolt, Naval Proving Ground. From a consideration of conditions at the boundary of a source of shock in air, and of conditions at great distances, a formula of the Riemann type has been derived for the velocity of propagation of a finite pulse. Formula includes an additional constant which provides the necessary flexibility to represent data obtained throughout the fields of sources consisting of detonating charges of explosives, and of other sources.

Observations of wave displacements have been summarized in terms of an integral for "reduced" times, from which the constants of the function for velocity are immediately available. All distances are defined with reference to an equivalent dimension of the source, and the characteristics throughout the velocity field are obtainable from characteristics of the source. A table is given for velocity of a condensation pulse, for representative boundary velocities, at various distances from the source out to points at which velocity has decreased approximately to its asymptotic value (the normal velocity of sound). Results obtained by Wolff and Burlot for very large sources are shown for comparison on a plot of reduced times. Preliminary results, obtained with piezo-gages in experiments to determine relative pressures at the head of the wave, are given in comparison with theoretical gage pressures obtained by formulas derived in another article. *Acoustical Soc. Am., Jour.*, October, 1939, pages 233–244, 9 illus., 17 tables, many equations.

The Propagation of Shock Waves in Air—II. L. Thompson. By use of the Rankine-Hugoniot equation of condition and Hugoniot's velocity of a discontinuity in a gas, formulas are obtained for density and pressure at the head of a shock wave which are referred to velocity of the wave as a parameter. Gage pressures are defined in a form considered to represent the observations of pressure obtained in the preceding article. The function is used to calibrate the gage, and a comparison of results by Rayleigh's pressure function is included. Appropriate ratio of specific heats for condensation cycles so extremely short in duration as those of intense shock waves, with references to the literature bearing on the subject of the accumulation of molecular excitational energies in short intervals of time, is discussed. *Acoustical Soc. Am., Jour.*, October, 1939, pages 245–253, 3 illus., 2 tables, 17 equations.

Predetermination of the Turbulent Diversion Point. F. Schultz-Grunow Goettingen. The decelerated turbulent boundary layer flow is too complicated to enable exact calculation. The semi-empirical method of calculation, successfully worked out by Gruschwitz, is not generally applicable, however, to the immediate proximity of the diversion point, and therefore cannot supply sufficiently accurate statements as to the beginning of diversion. A supplementary evaluation of test fundamentals on the decelerated turbulent boundary layer is therefore presented. *Luftfahrtforschung*, August 20, 1939, pages 425–428, 11 illus., equations.

The Analogy Between Fluid Friction and Heat Transfer. T. von Kármán. Results of the modern turbulence research on velocity distribution near solid wall are applied to extend Reynolds' analogy between fluid friction and heat transfer to liquids. Discrepancies between the experimental results and the theory of Taylor and Prandtl are explained. New theoretical formula which fits the experimental results more satisfactorily is suggested and compared with the empirical equations of Dittus and Boelter. The fundamental idea of Reynolds' analogy can be applied with success to the problem of friction and heat transfer between fluid and solid, but recent experiments make it doubtful whether the same idea is applicable to exchange phenomena between fluids flowing with different velocities. It seems that in this case exchange of heat occurs at a relatively higher rate than exchange of momentum. *A.S.M.E. Trans.*, November, 1939, pages 705–710, 5 illus., 42 equations.

Aircraft Design

Effect of Wing Loading, Aspect Ratio, and Span Loading on Flight Performance. B. Goethert. In high-speed flight the most favorable wing loading G/F, at which maximum speed reaches its greatest value for a given aspect ratio is presented by the following relation: $G/F = (\rho/2)V^2_{max.} \times \sqrt{\pi\lambda C_D(\text{profile})}$, *i.e.*, an increase in the wing loading is worthwhile especially for high speed airplanes at low altitudes, whereas for slow flight no appreciable advantage is obtained. Best wing loading increases with aspect ratio, with profile drag coefficient and with a decrease in altitude. In consequence of the flattish curve of optimum speed against variation of wing loading, it is often useful to keep considerably below the most favorable loading. Resulting loss in maximum speed increases with flying speed and aerodynamic efficiency of the aircraft. In future development, therefore, choice of wing loading will become more important. With high-powered aircraft aspect ratio is less important.

In agreement with conditions for flight at maximum speed, the best wing loading for climbing increases with increasing engine power, aerodynamic efficiency, aspect ratio and profile-drag coefficient, and with decreasing altitude of flight. For modern aircraft, best wing loadings lie at smaller values than those adopted but present losses in climbing performance could be largely balanced if increase in wing loading were accompanied by an increase in aspect ratio. Susceptibility to variation of best wing loading decreases as propeller efficiency and engine performance grow less and all-up weight increases. The aspect ratio has only a slight influence on rate of climb. Variation is worthwhile only when losses in climbing caused by high wing loadings (necessitated by high speed flight) may be kept small. Abstract of D.V.L. report. *Aircraft Engineering*, October, 1939, page 391. Complete article. *Luftfahrtforschung*, May 20, 1939, pages 229–246, 31 illus., 18 equations.

Aerofoils with Many Parameters. W. J. Duncan. The family of airfoil profiles presented is sufficiently comprehensive to meet all practical requirements, and has the merit that the ordinates of the profiles can be very easily calculated. Profiles are all symmetrical, but can be converted into unsymmetrical airfoils by plotting the ordinates from any chosen curve midline. Apart from mere size the family depends on four parameters: position of maximum ordinate measured from the leading edge and expressed as fraction of chord; nose parameter; tail parameter; and thickness parameter. All the members are "fair" forms with round nose and sharp tail when the parameters have reasonable values, but the family includes aerodynamically vicious as well as good profiles. By suitable choice of the parameters close approximations to known good airfoils may be obtained. *Aircraft Engineering*, October, 1939, pages 383–384, 394, 5 illus., 1 table, 25 equations.

Armoured Aeroplanes. C. G. Grey. Comments on experiences with armored and unarmored airplanes during the war 1914–18, references to the Sopwith armored Salamander and Junkers armored trench-strafing airplanes of 1918, and the suggestion that a suit of armor be devised which could be fitted temporarily under any airplane which was being used for trench strafing. Reference is made to the use in Spain of the Savoia-Marchetti three-engine bomber which was considered a favorite ground-strafing machine since, when all its bombs were dropped, it was very maneuverable for ground strafing. *Aeroplane*, October 19, 1939, pages 476–477.

Fixed Slit-Slots on the Lockheed 14. C. L. Johnson and R. L. Thoren. Angle-of-attack indicator, wing changes investigated, and fixed slot tests. Concluded. Last half of article from the Journal of the Aeronautical Sciences, September. *Aeroplane*, October 19, 1939, pages 486–488, 6 illus.

"Floating Lift." In the airplane design patented by Capt. F. T. Courtney, the wings are free to pivot about the main spar. Stabilizers, attached by booms, have hinged portions operated by the normal control column. Because the cables pass through hinge points of the wings, inherent stability of each wing is independent of the fuselage. Attitude of the fuselage is kept in the line of flight by adjustment of the normal elevators—now rather trimming tabs than elevators. Controls are reduced to two, and one other control becomes occasional. Maximum incidence which could be put on the wings would be kept just below the stall—by limiting the stabilizer movement. Machine could therefore be flown very slowly without danger of stalling and spin would be impossible. Slots and flaps could be applied to the full span as no ailerons are used, and full angle of greatest lift could be used without necessitating impossible positions of the fuselage. As fuselage is independent of wing angles, undercarriage can be designed independently of usual takeoff and landing requirements. Torsional stresses would be taken entirely to the booms.

Long description, and diagrams showing possible layouts of airplanes with floating-lift control and alternative arrangements for large multi-engine airplanes. *Aeroplane*, October 19, 1939, pages 484–485, 2 illus.

Problems of Submerged Engine Installations. W. E. Beall and E. G. Emery, Jr., Boeing Aircraft Company. Main problems which confront aircraft designers interested in submerged engine installations are described, including: design of a satisfactory propeller shaft; satisfactory and safe disposal of the exhaust gases; overall cooling of the engine compartment, cylinder cooling, supercharged air cooling, lubricating oil cooling, accessory cooling, and exhaust disposal system cooling; and mounting of the engine.

Problems encountered by Boeing engineers in making preliminary designs of several types of advanced aircraft with submerged engine installations are considered. Thickness and length dimensions of engines are of utmost importance, making it extremely difficult to design an aerodynamically good wing for high-performance aircraft. Effect of inside installation on aerodynamic form of the wing and its structure, ease of access to the engine and accessories, propeller shaft, cooling air for liquid cooling of engines, ventilation of engine compartments, design of the exhaust disposal system, effect on structure of exposure to excessive temperatures of the power plant installation, installation of turbo-supercharger, extra weight of the engines worked with in preliminary designs, and its effect on installation are discussed. Advantages are almost entirely gains in aerodynamic performance, including: increased propulsive efficiency due to lack of propeller interference with nacelles; increased lift because much smaller extension shafts do not blanket or prematurely stall the wing as with larger nacelles; reduction of drag due to elimination of large nacelles; and elimination of wing-nacelle interference. *S.A.E. Preprint for National Aircraft Production Meeting*, October 5–7, 1939, 7 pages.

The Unaccounted Drag of Aircraft. F. W. Lanchester. If the actual airplane is flown at the calculated speed of least resistance, that is calculated without parasitic drag, then the factor (ratio of unaccounted drag to that calculated) will be truly determined. If the actual airplane is flown at its velocity of least resistance, that velocity will be lower than that given by calculation because the body resistance (hence the whole direct resistance) having been increased by the parasitic drag, the resistances varying directly as V^2 will no longer balance the induced drag varying inversely as V^2 and the velocity V must be reduced.

The author regards with suspicion the low wing, on the basis of aerodynamic considerations. He believes that it is certainly disadvantageous to place the body above the airfoil, for in that region the air has a higher velocity of relative motion than in the region beneath. When body resistance is calculated on the basis of skin friction, or from data secured in the wind tunnel, it needs to be credited with profile drag on the missing part of the airfoil.

In regard to boundary layer control as a means of diminishing skin friction, he considers that, in the case of organs possessing much thickness (wing sections or body form), the result of delaying or abolishing the turbulent condition would have the undesirable result of encouraging the onset of burble and would give rise to an increase in profile drag or body resistance. Beyond the systematic elimination of the causes of parasitic drag and closer study of body form and body position in relation to organs of flight, the most promising outlook for further development and improvement in performance factor is thought to lie in refinements in and connected with the engine, in particular the housing and cooling arrangements, also in the induction and exhaust systems. *Engineering*, October 13, 1939, pages 403–406, 3 illus., 1 table.

Engineering Lessons on Active Service. Stressed-skin construction does not stand up well to hits by machine-gun bullets or shrapnel from anti-aircraft shells. Where fabric is merely perforated, stressed metal skin is buckled and torn in ways that may affect the flying characteristics. Certain airplanes are already gaining an unhealthy name as "flamers"—the German Messerschmitt is one. Long take-off run necessary with some heavily-loaded monoplanes is a handicap in operation from advanced airports. Fast landing and sloppy control at slow speeds make night flying from darkened airports unduly dangerous. Short note. *Aeroplane*, November 2, 1939, page 548.

Interference Drag between Wing and Fuselage (Evaluation of American Measurements). W. Haack. American measurements on different wing-fuselage combinations, obtained by E. N. Jacobs and E. Ward in the N.A.C.A. high pressure wind tunnel, are evaluated in such a manner that, for two different flight conditions (high speed and climb) and with use of a rectangular wing and round fuselage, a direct comparison of the combination drags at different high positions of the wing and wing-root casing is possible. By additional illustration of computed combination drag, the drag portion which may be attributed to mutual interference is obtained. The influence of the wing or fuselage form and incidence of wing chord and fuselage longitudinal axis on the combination drag is determined. D.V.L. report. *Luftfahrtforschung*, August 20, 1939, pages 419–424, 13 illus.

Killing the Stall. W. E. Gray. Fresh attack on the problem which is said to aid landing technique, and description of model and full-scale tests that have been carried out in the study of its possibilities. Method consists in the spoiling of the airflow at a chosen point near each wing tip, avoiding a sudden large breakdown of the flow. If applied to a tapered wing (for which maximum lift cannot be obtained except in actual landing, owing to the pilot being nervous of its stability at the lower speeds), then it becomes possible to fly with safety at a lower speed than before, despite any slight loss of maximum lift. Stabilizing effect is accompanied by an almost surprising steepening of the glide, as much as 10°, and landing is very short owing to the high drag.

Most striking features are the way in which the airplane can be thrown about, even when fully stalled, by use of ordinary ailerons alone, and the complete absence of any tendency to fall into a spin in any circumstances. Airplane is merely provided with two small spoilers near the leading edge, placed at any position about 70 or 80 percent of the semi-span out along the wing. By leaving free a portion of the wing outboard of the spoiler, airflow there is preserved to quite a high incidence and damping in roll is improved. Only serious doubt arising is whether the treatment can be applied with equal results to flapped airplanes, full-scale evidence on this point being discouraging. *Flight, Aircraft Engr. Sup.*, October 26, 1939, pages 43–45, 3 illus.

Lift Distribution on the Wing with Side Plates. W. Mangler. For the case of minimum induced drag (constant induced downwash over the span) the lift distribution on airfoils with vertical plates was calculated for a few characteristic conditions. From this, curves for lift and induced drag of airfoils were interpolated for any chosen dimensions of and modes of attachment of the plates. Lateral forces occurring at the end plates were determined.

Point of action of the lateral forces lies at about 40 percent of the depth of the upper or lower side of the plate. Total lift of the airfoil for a given angle of incidence increases with an increase in depth of plate and is maximum if plates are fitted as end plates. Lateral forces and moments also increase with depth of the upper or lower side of the plate, and have their greatest values when plates are fixed only on one side, as end plates, and otherwise when the plates are fitted near wing extremities. Lift and induced drag of the airfoil, outer extremities of which are deflected upward through the angle ϵ (U or V arrangement), were calculated. Total lift and the moment at the point of deflection increase with increasing ϵ and with increasing length of the part of the wing deflected upward. Short abstract of Goettingen report. *Aircraft Engineering*, October, 1939, page 391. Complete article. *Luftfahrtforschung*, May 20, 1939, pages 219–228, 24 illus., 53 equations.

New Method of Transfer of Model Resistance of a Vehicle Gliding on the Surface of the Water to Full-Scale Design. W. Sottorf. A new treatment for the problem of transferring model results to the full-scale aircraft is necessary due to the increasing size of aircraft. From an application of the analysis of investigations on gliding surfaces, the curve of the wetted surface is determined mathematically over the take-off range. The friction coefficients can be derived from the Prandtl curve for turbulent boundary layer with laminar starting. With these two values a friction correction may be determined. Method is described and examples are given to show the suitable approximation determined by calculation and the resistance curve derived from measurements. An old-scale series with the application of the correction gave good agreement of the three resistance curves. The step from 10-ton to 100-ton flying boats, by application of the correction, was established as not critical for the transfer from a model to the present normal size. D.V.L. report. *Luftfahrtforschung*, August 20, 1939, pages 412–418, 9 illus., 11 equations.

The Schuler Principle for the Acceleration-Free Resonance. E. Schmidt. It is shown that the Schuler principle for the deflection, free from acceleration, of a physical pendulum, holds good for any chosen acceleration of aircraft. For the case when a pendulum is suspended, not from a point, but from a universal joint, certain limitations apply. Earlier hypotheses to the contrary were affected by an error, which is pointed out. Addition to the article "Remarks on the Pendulum Having a Period of Oscillation of 84 Minutes" in the 1938 Yearbook of the Deutschen Luftfahrtforschung. Brief abstract. *Aircraft Engineering*, October, 1939, page 391. Complete article. *Luftfahrtforschung*, May 20, 1939, pages 247–250, 4 illus., 9 equations.

Stress Analysis and Structure

Shell Construction with Longitudinal Panels. W. Rethel. The Arado method of construction described was evolved with the following objects in view: manufacture of a shell-type fuselage with double curvature by a method avoiding panel beater work while obtaining an accurate adherence to given contour lines; use of normal tools without any special fittings; standard parts which can be used for several types of fuselages; adaptability to machine riveting or to electrical spot welding; and use of strip material for the shell-skin planking. Description of construction and Arado method of production. Stringer profiles are formed by flanging the longitudinal edges of each second consecutive strip. Translated from Jahrbuch 1938 der deutschen Luftfahrtforschung. *Aircraft Engineering*, October, 1939, pages 398–399, 12 illus.

Type Solutions. J. B. B. Owen. Three methods of solving complex problems in redundant frameworks or vibration are pointed out, and "type solutions" are constructed which reproduce some of the properties of the required systems. Each "type solution" then gives its own physical picture of the problem and the procedure minimizes the number of "type solutions" which have to be combined to give a reasonably correct approximate solution. Applications to beam problems and to vibration problems are discussed in great detail. Synchronous speeds corresponding to higher harmonics of natural frequency may be obtained and the solutions checked in a similar manner. The method may be developed also to deal with propeller vibration and flutter problems. *Aircraft Engineering*, October, 1939, pages 387–390, 394, 9 illus., 3 tables, 24 equations.

Aluminium Alloys in Aircraft. W. C. Devereux. Metallurgical achievements contributing to the use of aluminum alloys in aircraft in recent years, and suggestions for future development. Aircraft design factors are briefly considered including: stress-carrying capacity of the sheet-panel and its supporting structure, requirements of aircraft structure to meet the increase in speed, and lack of strength of sheet-to-sheet joints which seriously limits the usefulness of high-strength light alloy sheets. Percentages of light alloys by weight and volume which are used in liquid-cooled inline engines and in air-cooled inline and radial engines are given in a table.

In regard to extrusions, the metallurgists have not been able to satisfy fully the demands of the aircraft industry and problems to be solved are pointed out. Unless better cast materials are forthcoming for cylinder heads for poppet-valve engines, it will be necessary to turn to wrought forms, and much ingenuity is being shown in methods of stamping for this purpose. The Phillips and Powis "Master" fighter-trainer, of wood construction, includes 360 separate castings in magnesium alloy of which 235 are different. Use of forgings, stampings, sheet pressing and drop stamping in aircraft and propellers are briefly touched upon.

Research proposed to further the use of aluminum alloys in aircraft includes: use of heat-treatable alloys in a softer or partially softer condition; design of component coupled with heat treatment at a subsequent stage of machining to ensure that internal stresses be opposed to direction of applied forces and that these stresses will not be disturbed by subsequent machining; and selective heat treatment, meaning insulation of parts of a component during quenching to ensure that internal stresses will not be additive to applied stresses. Paper intended for Aluminium Congress at Zurich. *Metal Industry*, November 3, 1939, pages 385–389, 5 illus., 1 table.

Calculation of the Section Properties of Aerodynamic Profiles. O. Steinitz. Several methods have been developed by the author for use in computing the stress of intricately shaped cross-sections, and have been proved, by practical application, to offer a satisfactory solution. The formula upon which the calculations are based is $W = F/(c \times b)$. A formula is developed which does not require the calculation of the moment of inertia but the section modulus results immediately from the width b and the area F of the cross-section which are easily calculated from the drawing, the area F being measured by a planemeter. Formulas are applied to calculation of the bending stress for the cross-section, the full cross-section, the hollow cross-section, and the compressive strength. *Aero Digest*, November, 1939, pages 37, 124, 3 illus., 4 equations.

Calculation of Torsion of Box-Shaped Beams, One Wall of Which Is Lacking. E. Cambilargiu. Torsion of box-shaped beams with rectangular cross-section, one external wall of which is lacking, and the edges of which are reinforced by flanges, is computed according to the energy method. Torsional stresses are principally absorbed by bending of the two parallel walls, the stiffness of which is increased by the third wall. Result is tested experimentally on box spars of duralumin and plywood. Due to internal stiffening the measured torsions are from 10 to 30 percent less than the computed values. *Luftfahrtforschung*, August 20, 1939, pages 403–411, 12 illus., 4 tables, 49 equations.

Design for Spot Welding. C. F. Marschner. Allowable design values for spot welds in single shear, and ultimate design stresses for tension loads in the sheet normal to a line of spots in Alclad 24ST and 52S are considered,

and data are given in tables. In attempting to develop a practical inspection method, the author found that there is a very definite relationship existing between the "dimple" diameter, the weld diameter as measured in the plane of the sheets, weld strength, and welding amperage. If welding tips of uniform shape are used, it is possible to predict weld strength with reasonable accuracy, especially for heavier gages, by merely measuring the dimple diameter. Dimple and weld diameters which correspond to allowable design values are given in a table. Conditions indicated by cracks are explained. Design notes on 52S, plain 24ST, and Alclad are presented. *Aero Digest*, November, 1939, pages 40–41, 124, 8 illus., 3 tables.

Flutter Speed. J. C. K. Shipp. Routine method for determining flutter speed of a conventional cantilever wing. It is assumed that the wing is semirigid, *i.e.*, the modes of deformation in flexure and torsion are independent of the aerodynamic forces. Elastic deformation of the wing is represented in terms of the flexure and twist at some typical reference section. There are eight wing characteristics or "derivatives" to determine before the flutter speed and frequency can be considered. Inertia, stiffness, and damping derivatives are dealt with. *Flight, Aircraft Engr. Sup.*, October 26, 1939, pages 45–46, 335, 2 illus., 22 equations.

The Fundamentals of Stressed-Skin Construction. H. E. J. Rochefort. Paper published in the June 14th and 21st issues of the magazine is discussed by W. Tye. The author's replies are included. *Aeroplane*, November 9, 1939, page 578.

The Stressing of Rotating-Blade Aerofoils. J. B. B. Owen. Evaluation of bending stresses in blades of a propeller, helicopter, or gyroplane. Thrust is distributed along the length of the blade, and it is assumed that its intensity at all sections is known, so that attention may be concentrated on the bending of the blade caused by a given air loading. Discussion covers: transverse loads; blade bending; construction of a "type solution"; solution for a blade with a hinged root; use of type solutions; gyroplane blade problem; choice of M curve; and first and second approximations. Paper presented before the British Association. *Engineering*, November 3, 1939, pages 511–513, 10 illus., 9 equations.

Aircraft Accessories

Design and Shop Problems in High-Pressure Hydraulic Systems. H. W. Adams, Douglas Aircraft Company. Decrease in weight with increase in pressure; the Margin of Safety for low-pressure and high-pressure systems; problem of solid lines which resolves itself into one of choosing higher-strength materials as the pressure is increased in order to keep in the available range of wall thicknesses; wrench torque required to seal fittings; V-ring and cup-type packings commonly used in hydraulic systems; precautions in design of cylinders, pumps, and valves for high-pressure systems; collapsing of tubes subject to external pressure, which can be critical on cylinders having large-diameter piston rods; problems in the design of main pressure pumps driven from the airplane's engines, and solutions in the single-stage high-pressure pump, multistage gear pump, multistage pump having one stage on each engine, and variable-displacement piston pump now available in Europe; design of valves for high-pressure systems; and finishings on surfaces over which packings slide under pressure. *S.A.E. Preprint for National Aircraft Production Meeting*, October 5–7, 1939, 9 pages, 3 illus.

Aircraft Manufacture

Multiple-Gang Flush Riveter. Multiple-gang flush riveter developed by General Engineering Company will head in one operation, in a single stroke, 10 to 16 flush-type rivets along a straight line and on flat sections such as for the attachment of stiffening channel to a section of skin. Description of machine and its operation. *Aero Digest*, November, 1939, page 115, 1 illus.

Accelerated Aircraft Production for National Defense and Some of Its Effects on Organization and Personnel. P. N. Jansen, Curtiss Wright Corporation. Problem of producing the prototype; the present Air Corps procurement plan, called "the purchase of paper airplanes"; lot system production; need for control of quantity, quality, and schedules through planning purchasing and factory; service troubles; tooling; aircraft manufacturers' responsibility; outside vendors; a plan for expansion; effect of changes to present-day designs; the human element; planning and control; equipment; tool storage; and overhead. *S.A.E. Preprint for National Aircraft Production Meeting*, October 5–7, 1939, 9 pages.

The Final Assembly of Aircraft. H. F. Schwedes, North American Aviation, Inc. Requirements for the production of airplanes at a rapid rate include: a well engineered airplane, not only for performance but for manufacturing as well; careful planning; a good schedule; production control in order to hold various departments in line with schedule; proper distribution of labor through the subassembly of component parts; issuing of these subassemblies as complete as possible to final assembly; and an assembly line set up by position through which ships move in an orderly manner on a prearranged schedule. Explanations are given for photographs of aircraft in various stages of production which are not shown in the preprint. *S.A.E. Preprint for National Aircraft Production Meeting*, October 5–7, 1939, 5 pages.

Henschel Theories on Production. O. Oeckl. Main objects of the firm were to cheapen metal airplane production, to enable quick changes to be made from one type to another, and to develop tools and equipment suitable for production of metal airplanes. Jigs are made inherently stiff, stand on their own legs (little jacks) on the floor, and are equipped with castors. Inherently stiff types of structural members and standard parts are used for jigs, a special large scale "Meccano" system being devised. Jig attachments are shaped to wing profile and are used to check rib shapes after ribs are placed in the main wing jig.

Advice on the design of jigs and of dies of different materials for use in hammers or presses for sheet-metal work is presented. System of wiring by which all the wiring goes into one duct is described. Examples of aerodynamic and structural research work done by the company in cooperation with Goettingen and the D.V.L. are referred to.

Replacement of ordinary materials by plastics or magnesium alloys on a large scale, because these raw materials are easy to obtain, has often been discussed in Germany but such use is very far in the future.

Illustrations include: Henschel tubular jig; stretching blocks; molds and patterns for dies; erection jig for the Hs.126 main plane; a complete wiring assembly before installation and installed; and a strut with double end fittings after a fatigue test in which brittle varnish was used to follow surface strain. From "Henschel Heft." *Aircraft Engineering*, October, 1939, pages 395–397, 400, 12 illus.

Interchangeability in Modern Aircraft Production. C. J. Hertel, Douglas Aircraft Company. Methods used in the airplane industry to overcome the difficulties of interchangeable fabrication and assembly by means of adequate engineering data and by the use of tools and jigs peculiar to this industry which permit efficient fabrication and assembly method. Difficulties caused by the large size of parts, the prevalence of double-curvature surfaces and of the deflections of the structure are shown to be overcome by the application of analytical geometry, the use of lofting, and the construction of a number of subassembly jigs of a type peculiar to airplane production. *S.A.E. Preprint for National Aircraft Production Meeting*, October 5–7, 1939, 11 pages, 2 illus.

Job-Lot Aircraft Stampings. F. J. Oliver. Use of rubber pads in conjunction with simple dies of wood and metal has made the large-size hydraulic press one of the most useful tools in the manufacture of aluminum-alloy sheet-metal parts for all-metal airplanes in small lots. Blanking operations, advantages and limitations of the rubber-pad method of producing multiple stampings, and stretching and shrinking machines are discussed. Concluded. *Iron Age*, October 26, 1939, pages 43–47, 7 illus.

Some Machines and New Processes of Production of the S.N.C.A. S.E. P. Rodary. New machines and processes of fabrication developed and placed in service by the specialized service of the S.N.C.A. SE. (French aircraft manufacturers of the South East). The new "SE" fatigue machine described renders the fatigue tests of alternate bending simple and rapid. On a very resistant base are mounted successively a fixed vice, a grooved vice and an electro magnet which can be displaced in two perpendicular directions The "SE ' portable hammer for cambering, and the "SE" fixed machine for cambering, the "SE" new type of tubular rivet having a stepped bore and capable of being placed from the exterior in inaccessible places where ordinary rivets cannot be used, and a new procedure and tools for riveting are also described in detail. *La Technique Aéronautique*, No. 3, 1939, pages 114–134, 37 illus.

Aircraft

France

A French Sub-Stratosphere Flight. A flight in the substratosphere across the South Atlantic was completed on October 13th when a Farman machine, equipped with a special cabin and oxygen breathing apparatus, arrived at Rio de Janeiro. Flight was made at an average heignt of 24,600 ft. and ceiling was 29,500 ft. Atlantic crossing was made in 12 hours. Machine was said to be a Farman flying boat. The Farman NC.2234 four-seater long-range bomber exhibited at the Paris Show last year was powered by four 1000-hp. Hispano-Suiza 12-Y 12-cylinder Vee liquid-cooled engines driving three-bladed Hispano-Suiza metal c.p. propellers. Range at 217 m.p.h. was said to be 4960 miles. Brief note. *Aeroplane*, October 26, 1939, page 522.

Germany

"A.C." Types of the Luftwaffe. H. F. King. German reconnaissance and observation aircraft. Henschel Hs.126 parasol strut-braced high-wing monoplane (B.M.W. 132 Dc or the Bramo Fafnir engine developing, respectively, 870 hp. at 8200 ft. and 830 hp. at 13,800 ft.) has sweptback wings and fixed undercarriage. Trailing-edge flaps of the camber-changing type are fitted inboard of the slotted type ailerons and extend as far as the large vee-shaped cutout in the center section. Machine may be equipped for reconnaissance, artillery observation, light bombing, or laying of smoke screens and for day or night missions. Armament, photographic and other equipment, design and construction are discussed. Data are given for the machine when fitted with a Bramo Fafnir 323 fully-supercharged engine, as well as for performances as a photographic aircraft (top speed 230 m.p.h. at 16,400 ft.).

Fieseler Storch Fi.156 three-/four-seater high-wing monoplane is noted for its slow-flying capabilities and ability to operate from confined spaces (minimum speed 32 m.p.h., landing speed just over 25 m.p.h.). As issued to army-cooperation units, it is fitted with the 240-hp. Argus As 10C engine. Performance is described.

Faster and larger twin-engine machines are used for strategical reconnaissance, such as the earlier versions of the Dornier Do.17 (two B.M.W. VI engines), and the later versions (Daimler-Benz D.B.600, B.M.W. 132 Dc and Bramo Fafnir engines). The Dornier Do.215 and short-nosed He.111 are especially suitable for observation purposes. References only are made to the Dornier aircraft. *Flight*, October 26, 1939, pages 334a-334d, 7 illus.

The Dornier Bombers. H. F. King. Development of Dornier bombers, and characteristics of the Do.17 and Do.215. Various models of the Do.17 differ only in design of nose, installation of military equipment, and power plant. Bombs are carried horizontally in the bottom of the fuselage behind the plane of the front spar, and external racks may be attached to the sides of the fuselage. A typical bomb loading would be about 1500 lb. The following figures might apply to the machine fitted with two Daimler-Benz D.B.601 engines but standard Service aircraft would not be so efficient: disposable load 6600 lb.; service ceiling 29,500 ft.; maximum speed 310 m.p.h.; range 1550 miles. All Do.17 models have a wing span of 59 ft., and wing area of 592 sq.ft.

Wing, fuselage, tail, power-plant installation and undercarriage of the twin-engine Do.215 bomber are similar to those of the Do.17 but a "swollen" nose section accommodates the crew. New machine can likewise be fitted out as a short-range heavy bomber, as a long-range bomber with smaller bomb load, for long distance reconnaissance, for ground-attack work, and even as a fighter. One gun protrudes through the starboard panel of the windscreen, one is on a manually operated pillar-type mounting in the upper position, and one in a hemispherical mounting fires below the fuselage. B.M.W. 132 Dc and Brano Fafnir radials and the D.B.601 inverted-vee 12 liquid cooled engines are normally specified. D.B.601 engines give the best performance but streamlining in comparison with that of the Do.17 is poorer. All up weight 18,960 lb. Disposable load 7270 lb. Range 1860 miles. Despite higher wing loading (about 32 lb./sq.ft.) it is claimed that landing speed is the same as that of the Do.17 (68 m.p.h.). Top speed is optimistically published as 310 m.p.h. Long descriptions of construction of both airplanes, photographs of both, and cutaway drawings of the Do.17, and of the "business end" of the Daimler-Benz powered Do.215. *Flight*, November 2, 1939, pages 350a-350d, 351, 6 illus. Few details, characteristics and three-view drawing of the Do.215. *L'Aerophile*, August, 1939, page 178, 2 illus., 1 table.

The Dornier Flying Boats. H. F. King. The Dornier Do.26 is one of the shapeliest and fastest flying boats in the world. Originally planned as a long-range mail-carrying type, it is believed to have been adopted by the Luftwaffe for long-distance reconnaissance and bombing. The Do.26 is characterized by a gull wing. Slim hull is of the two-step type and tail unit has a single fin and rudder. Two nacelles each contain two Jumo 205 Diesel engines in tandem. Without armament, top speed 208 m.p.h. Theoretical range 5600 miles.

Few details and photograph of the Do.26 but long descriptions and photographs of the Do.24 and Do.18. Sketches actually made from a Do.18 of the German Air Force at the Friedrichshafen works show the ingenuity displayed in disposing of the twin Jumo 205 Diesel engines, the rear engine driving its V.D.M. variable-pitch propeller through a shaft of considerable length. Another sketch shows the peculiar longitudinal steps and twin water rudders.

Drawings illustrate: gun turrets in bow, aft of wing, and in the tail of the Do.24; the tail gun position; and bombs slung beneath the wings outboard of the sponsons. Photographs of the navigator's compartment in the Do.24 and of the exterior of the Do.24 and Do.18 are included.

Layout of the Do.24 resembles that of the Do.18, being a semicantilever monoplane with "sea wings" to give lateral stability on the water. Three engines are installed in line abreast, the central one being slightly higher. Probably D.B.601 or Junkers Jumo 211 engines are used. Span 88 ft. 7 in. Top speed 195 to 210 m.p.h. Ceiling 18,500 ft. Range 2170 miles.

Twin-engine Do.18K is similar to the civil prototype Do.18 and has been discovered as a not very formidable adversary. Span believed to be 77 ft. 9 in. Ceiling a little more than 13,000 ft. Landing speed 60 m.p.h. Range not more than 2000 miles. *Flight*, November 9, 1939, pages 372a-372d, 11 illus.

Some German Seaplanes. H. F. King. Heinkel 115 general-purpose midwing floatplane (two B.M.W. 132Dc radial engines, top speed, 215 m.p.h., normal range 1300 miles) is among the most modern and efficient of the German seaplanes, and has been specially studied for nautical operation. Torpedo is stowed internally. A special version broke eight international seaplane records.

Arado low-wing monoplane (B.M.W. 132Dc engine) on a heavily-braced twin-float undercarriage is a recent type introduced for service on ships and is illustrated mounted on the catapult of the German pocket battleship "Admiral Graf Spee." The Arado Ar.95 Spee is a sturdy versatile biplane (B.M.W. 132Dc engine) and can be fitted as a torpedo carrier, bomber, reconnaissance machine, gunnery observation aircraft and for the laying of smoke screens and towing of targets. It can be operated on wheels or floats and is stressed for catapulting. Top speed as a seaplane 187 m.p.h. Climb to 13,120 ft., 11 min. Top speed as a landplane slightly more than 200 m.p.h.

The Heinkel He.59 and He.60 floatplanes were used in the Spanish conflict but are now regarded as advanced training aircraft. The He.59 is a large heavily-braced biplane (span more than 77⅓ ft., two B.M.W. VI 12-cylinder vee engines). He.60 is a smaller single-engine type (B.M.W. VI engine). Heinkel He.114 reconnaissance sesquiplane (B.M.W. 132Dc engine) has an upper wing span of 42 ft. 9 in. Short descriptions of these seaplanes, in some cases performance and armament, and cutaway drawing of the Arado AR.95 See. *Flight*, October 19, 1939, pages 316a-316d, 10 illus.

The Junkers Ju 86K. Junkers Ju.86K bombers are still in service in many squadrons of the German Air Force. They were in action over Poland and have been reported over the Western Front. Most of these bombers are powered with two 700-hp. Junkers Jumo 205-C heavy-oil engines. Maximum duration 9 hours at 174 m.p.h. with load of 2205 lb. of bombs stowed internally. Maximum speed 224 m.p.h. Newer versions powered with latest Junkers Diesels reach 238 m.p.h. Some versions with two 880-hp. B.M.W. 132Dc radials are in service, cruising at 214 m.p.h., but with range reduced from 1555 miles to 935 miles. There are gun positions in the nose, on top of the fuselage, and in the retractable dustbin beneath. Crew normally is four. Description of construction, armament, characteristics, performance, and cutaway drawing showing location of equipment. *Aeroplane*, October 19, 1939, pages 478–479, 3 illus.

Some German Military Types. More modern types of German military airplanes in service, together with some notes on their development and modification. Junkers Ju.89, bomber version of the large Ju.90 passenger-carrying type with which a number of curious accidents occurred, is equipped with gun turrets in nose and tail contrary to usual German practice. The civil Ju.90 has a maximum speed of 220 m.p.h. when fitted with four B.M.W. radial engines. Another new machine, the Junkers Ju.88, a comparatively small twin-engine monoplane with a slender fuselage (two 1200-hp. Jumo 211 liquid-cooled engines mounted in unusual cowlings), set up an International record of 321 m.p.h. for 621 miles with a 4410-lb. load in March. These two machines are referred to and the cowling of the Ju.88 is briefly described. Another potential large bomber type referred to is the Focke-Wulf FW.200 Condor (four 870-hp. B.M.W. 132Dc engines). Loaded to all-up weight of 33,334 lb., maximum speed 267 m.p.h. at 9500 ft. Range 1460 miles at cruising speed of 230 m.p.h.

Details and in some cases descriptions of construction and armament, characteristics, performances, photographs, and drawings are given for the following standard German bombers, fighter, Army-Cooperation, and seaplanes: Heinkel He.111K bomber; Dornier Do.17 twin-engine bomber; Dornier Do.215 (which may prove to be a pointer indicating the possible future trend of German bomber design); Junkers Ju.87 dive-bomber and reconnaissance airplane; Messerschmitt B.F.W. Me.109 and Heinkel He.112 single-seater fighters; Heinkel He.112 and He.112U record breaker; Messerschmitt Me.110 twin-engined fighter; Henschel Hs.126 Army Cooperation; and Heinkel He.115 floatplane.

Coloring of German military airplanes has a distinct bearing upon their aerodynamic performance owing to the texture of the paint, and the surfaces appear to be well filled and rubbed down. Although actual rivet-head marks and dimples are usually covered, actual panel irregularities are large. German camouflage consists entirely of indefinite colors rather than an attempt to imitate any actual ground colorings. *Aircraft Engineering*, October, 1939, pages 375–379, 382, 23 illus., 5 tables.

Heinkel He 111K Two-Motor Bomber. The Mk. III, long-nosed version of the He.111K bomber, (two 1050-hp. Junkers Jumo 211 engines) has a top speed of 255 m.p.h. at 13,120 ft. while that of the short nosed Mk. V. version (two 1150-hp. Daimler-Benz D.B. 601A engines) is 274 m.p.h. at 12,300 ft. Bomb cell is in the center section with stowage for up to 4410 lb. of bombs. Some of the He.111K bombers may have been modified to take 1102 lb. bombs, but eight 550 lb. bombs are the largest which can be carried in the normal version. The Mk.V has a 0.312-in. machine gun in the nose on a universal mounting, hand operated, a second gun on top of the fuselage sheltered by the sliding transparent hood, and a third gun in a well-faired emplacement below the wing. Wing span of the Mk.V 74 ft. 3 in. Length 54 ft. 6 in. Disposable load 12,000 lb. Wing loading 26.45 lb./sq.ft. Stalling speed 81 m.p.h. Initial climb 890 ft./min. Time to 13,120 ft. 16.8 min. Service ceiling 24,100 ft. Range 2140 miles, with over load 2640 miles

Long description of the Mk.V (two 1150-hp. D.B.601A engines) as well as cutaway drawing showing location of equipment and structure, and table of characteristics (weights, loadings, capacities, and fuel consumption) as well as of performances. Another table gives the characteristics of the various He.111Ks (Mk. I, Mk. II, Mk. IIA, Mk. III, Mk. IV, and Mk. V) including engines and maximum speeds with armament retracted and extended. Another drawing illustrates how the Mk.V bombers are assembled at Oranienburg. He.111K bombers took part in the action against Poland against squadrons of the Royal Navy in the North Sea, and in the raid on the Firth of Forth. *Aeroplane*, November 2, 1939, pages 542–544, 8 illus., 2 tables.

Messerschmitt Me.109 Fighter. Quite recently the version of the Me.109 with the 1150-hp. D.B.601 engine has gone into squadron service. It retains the three radiators which work on the fully-ducted principle with low-velocity cooling. Backward-facing ejector exhausts, and a better-formed cowling are other new features. Fully-cantilever wings are built with a straight taper and square-cut tips. Construction is entirely of metal built around a single spar with a metal stressed skin, flush rivetted. Airplane is nice to fly and aileron control in particular is brilliant. Like the Taifun, the Me.109 can be tipped from one wing tip on to the other in the brief time in which the stick can be pushed over.

Description of design, construction, and performance and cutaway drawing of the version powered by the 1150-hp. D.B.601, showing location of equipment and construction. *Aeroplane*, October 26, 1939, pages 512–513, 2 illus.

ITALY

A Fast Italian Bomber. Breda 88 two-engine light bomber (two 1000-hp. Piaggio P.XI RC-40 radial engines) now in production and equipping a number of squadrons of the Regia Aeronautica, is one of the fastest airplanes of its class in the world (top speed 352 m.p.h. at 13, 120 ft. with full military load, and range 1120 miles). High speed is not gained at a sacrifice in range or load. The prototype set up new international records in 1937. Military load includes a crew of three, bombs, two fixed shell-firing guns in the nose, and a machine gun in a movable turret on top of the fuselage. Claimed landing speed of 69 m.p.h., obtained with use of Handley-Page slots and slotted flaps, suggests a wing loading of about 31 lb./sq.ft. Span 51 ft. 0 in. Disposable load 4850 lb. Climb to 16,400 ft. 11 min. Ceiling 28,000 ft. Description of design and construction and a few figures on characteristics and performance. *Aeroplane*, October 26, 1939, page 519, 2 illus.

A New Seaplane Record. Italy has set up a new world's height record for seaplanes of 40,700 ft. Time for the flight was 1 hr. 58 min., and the pilot was Col. N. Mauro. Brief ref. *Aeroplane*, October 12, 1939, page 461.

U.S.A.

Engineering Background of the C-W Transport. G. A. Page. Development of the Curtiss-Wright transport airplane now nearing completion at St. Louis, including: considerations of operating economy and pilot fatigue followed in designing the airplane; the "Tell-Tale panel"; full-feathering propellers; design of landing gear; enclosed flap mechanism; facilities for comfort; and structure of the airplane. *Aero Digest*, November, 1939, pages 46–48, 51, 124, 5 illus.

Rearwin Sportster Model 9000KR. Sporster Model 9000KR is a high-wing strut-braced two-place tandem monoplane with full N.A.C.A.-type cowl set flush with the contours of the fuselage except on the underside. Ken-Royce Model 5F 90-hp. engine. Wing span 35 ft. Maximum speed 125 m.p.h. Landing speed 38 m.p.h. Cruising range 500 miles. Description. *Aero Digest*, November, 1939, page 107, 2 illus. *Aviation*, November, 1939, page 43, 3 illus.

U.S.S.R.

Soviet International Speed Record. New record was recently set up by the Soviet pilots, N. P. Shabanov and V. A. Matveyev and N. A. Baikuzov, when they flew nonstop over a 3149-mile closed triangular course in 12 hr. 30 min. 56 sec., averaging 251.615 m.p.h. between Moscow–Sverdlovsk–Sevastopol–Moscow. Airplane was a Stal-7 passenger machine of Soviet manufacture fitted with two 960-hp. engines. They carried no payload. Bf. ref. *Flight*, October 19, 1939, page 316.

Aircraft Assisted Take-Off

The Atlantic Service Refuelled. A. J. Cobham. Experiences gained in fifteen contacts and transfers of fuel in flight to Imperial Airways flying boats of the North Atlantic services. Two Harrow tanker airplanes operated at Newfoundland and one at Foynes, Ireland. In general refueling operation took 12 to 15 min., about 5 min. being spent in making contact and getting the hose down, and 7 min. in passing the fuel. No difficulty in refueling at night is foreseen. Development of new equipment for safe operation at night is described. *Flight*, November 2, 1939, pages 358–359, 2 illus.

Air Transportation

Aviation in Australia. Developments occurring within the last twelve months include: use of ultra-shortwave radio beacons on inter-capital routes; Melbourne to Perth route and return covered by a Douglas in one day; all airlines subsidized to enable them to run at a reasonable profit by temporary six-month contracts; air services coordinated and rationalized; all-metal American aircraft on every main route; Commonwealth Aircraft Corporation in production with "Wirraways"; fifty Lockheed Hudsons ordered by the Royal Australian Air Force; and a government scheme to manufacture Bristol Beauforts. *Flight*, November 9, 1939, pages 363–366, 6 illus.

"Business As Usual." After a brief interruption at the outbreak of the war, British commercial aviation can now be said to be going quite strongly. The most outstanding record has been achieved on the Empire routes. Services now in operation are described. *Flight*, November 9, 1939, pages 374–376, 3 illus.

Civil Aviation in Malaya. Air transport services, meteorological stations, landing grounds in use, and club flying. Short review of report by Major R. L. Nunn, Director of Civil Aviation, for the year 1938. *Aeroplane*, November 2, 1939, page 556.

Civil Aviation in New Zealand. Second annual report on civil aviation in New Zealand for the year ending March 31, 1939, giving operating statistics for scheduled aircraft services and airline companies. *Aeroplane*, November 9, 1939, page 584, 2 tables.

Air Transportation

Notes on the Danish Company "Det Danske Luftfartselskab." Development of the D.D.L. since its start in 1918, mileage since 1936, and aircraft in use are discussed.

A second article describes the A.B.A. Swedish airline and a brief note gives traffic statistics for the Aero O.Y. airline of Finland. *L'Aéronautique*, August, 1939, pages 316–320, 13 illus.

The Patient is Recovering. British and other air-transport services which are starting up again after having been discontinued since the opening of the war. Results of the British Atlantic season, and the effect of war on Canadian air services are discussed in other short notes. *Aeroplane*, October 19, 1939, pages 492, 494.

Propellers

Argus Products. Mechanism of the variable-pitch propeller of the German Argus Company, the propeller brake, wheel with a lateral brake, and

the adjusting pedal for operation of the brake pump are illustrated in drawings and described. *L'Aéronautique*, August, 1939, page 321, 4 illus.

Propeller Production Methods Past and Present as Practiced by Hamilton Standard Propellers. A. Nelson, Hamilton Standard Propellers. Developments in Hamilton Standard propellers are reviewed, and present methods in use today to produce the quick-feathering Hydromatic propeller are described. Explanations are presented for photographs of various types of machines used in production, which are not shown in preprint. *S.A.E. Preprint for National Aircraft Production Meeting*, October 5–7, 1939, 12 pages.

Effect of Centrifugal Force on the Bending Natural Frequencies of Propellers. J. Meyer. Data on the frequency of bending harmonics of propellers, for the consideration of centrifugal force, differ in various publications. This discussion supplements the article by F. Liebers entitled "Calculation of the Three Lowest Bending Frequencies of the Rotating Propeller," the purpose of which was to test the reliability of the methods of calculation. D.V.L. report. *Luftfahrtforschung*, August 20, 1939, pages 429–430, 2 illus., 1 table, 11 equations.

Acoustics

Sound Insulation Characteristics for Ideal Partitions. K. C. Morrical. Present method of evaluating the effectiveness of sound insulative structures on the basis of mean values of T.L. (transmission loss) is inaccurate and unscientific in that it does not predict the performance of the unit in practice. Transmission characteristics of ideal partitions, or partitions which reduce the incident sound to a uniform loudness level, are derived from a consideration of intensity and frequency distribution of typically encountered speech and music and of the mechanism of hearing. It is shown that a family of these characteristics can be used as a means of predicting the insulation furnished by a particular structure and its manner of failure. Manner of extension of this method to ascertain the merit of a partition for different types of sounds is given. *Acoustical Soc. Am., Jour.*, October, 1939, pages 211–215, 4 illus., 1 table.

The National Physical Laboratory. Research in the Physics Department, including: measurement of sound; noise abatement; acoustics of buildings; sound transmission through walls, floors, and pipes; measurement of optical radiation; thermopiles; surface finish of metals; color matching lamps; and photographic lenses. *Engineering*, November 3, 1939, pages 494–496, 1 table.

Aircraft and Navigation Instruments

Air-Equipment Vacuum Pump. Vacuum pumps utilized for maintaining the depression in the interior of gyroscopic instruments are illustrated in drawings, including the Roots pump, pump with conchoidal body, pump with centrifugal blades, and pump with centered blades. In the pump of Air Equipment, the blades are no longer floating but are articulated on a central axis and are always normal to the pump body. Their contact with the latter moves a cylindrical surface of a width equal to their depth. Long description of the Air Equipment pump and its operation, as well as drawings of parts. *L'Aéronautique*, August, 1939, pages 321–324, 11 illus.

Comparison of Various Control Problems with Respect to the Suitable Regularity. W. Oppelt. Mutual comparison of pressure regulator, r.p.m. regulator, temperature regulator, and automatic vehicle control. The regulator free from error is separated from the imperfect actual control, and the analysis is extended in a parallel manner to the control systems discussed. Such a method of consideration, especially in its extension to the errors of actual controls, gives a far-reaching insight into the mechanism of the control process. The conditions of the systems to be regulated, the suitable regulator laws, the working together of regulator laws and system regulated, the error-free regulator, and the actual regulator (the slow regulator, the regulator affected by vibration, and the regulator with friction) are described. *Luftfahrtforschung*, August 20, 1939, pages 447–472, 3 illus., 7 tables, 46 equations.

Expanded Line of Aircraft Instruments. New instruments which use a d.c. Selsyn, particularly developed for remote indication on aircraft, include: gasoline-tank, temperature and pressure gages, chronometric tachometer, and landing-gear and flap-position indicators. Few details only. *General Electric Rev.*, October, 1939, page 455, 1 illus.

The Navigation Timepiece. Commander P. V. H. Weems. Various timing methods used or prepared are considered, including: use of chronometer set close to GCT to which its error is applied to get GCT; comparing watch used with chronometer; standard second-setting navigation watch rated and set to either FCT or GST; second-setting watch reading in arc—the Lindbergh hour-angle watch, rated to either civil or sidereal time; siderograph, rated to either civil or sidereal time and giving time in arc by direct reading; the twenty-four hour timepiece giving either GCT or GST in both time and arc; and a GCT watch supplemented by the sidereal time converter. *Aero Digest*, November, 1939, pages 38–39, 2 illus., 2 tables.

Pity the Poor Pilot. F. Chichester. Plea for transferring some of the equipment on transport airplanes to the care of the engineer officers, navigating officers, and radio operators. Too much is demanded of the modern air pilot. He has numbers of levers and controls to manipulate and, in one modern instrument layout, no fewer than 64 instruments to watch. Engineer officer would relieve the pilot of about forty instruments for the engines alone. He should also attend to fuel supply and distribution, take charge of undercarriage winding gear, according to the pilot's instructions, attend to all electrical equipment, see that flaps are working properly, operate the deicer control and look after the automatic control. Navigating officer will relieve the pilot of the rest of the instruments and duties. A captain to command the large transport is another suggestion offered. *Flight*, October 26, 1939, pages 334g–334h, 1 illus.

Testing Equipment

Artificial Altitude. New French plant for low-temperature tests of instruments and personnel has been designed and installed by the French Service of Aeronautical Research and the National Meteorological Office. Temperature and pressure conditions occurring during ascent can be produced progressively by artificial means up to those occurring at an altitude of 34,000 ft. Output of the refrigerating plant is large enough to allow the air to be changed with sufficient frequency for the pilot to breathe comfortably under normal conditions.

Inner lining of very loose insulating material has been provided for the test chamber instead of outer lagging. Material used must not be affected by the degree of humidity in the chamber or by alteration in temperature. A layer of Kapok 6 in. thick complied with these requirements. Under normal conditions, it has been possible to lower the temperature to −30°C. within 40 min., and air can be cooled down to −42°C., the temperature of petroleum then being −45°C.

The two-stage refrigeration plant, test chamber, instrument checking, and two systems by which temperature is maintained constant in the interior of the test room are described. *Flight*, November 9, 1939, pages 381–382.

Ice Elimination Equipment

Adel Anti-Icing Vane-Type Pump. Series F anti-icing pump has a pump speed slower than that of Series E, and the minimum capacities have been brought to less than 0.2 gal./hr. per outlet. Maximum flow is more than 3 gal./hr. Few details. *Aero Digest*, November, 1939, pages 115–116.

Miscellaneous Equipment

Flexible Pipe Union. Clay-Flex patented flexible pipe union. The synthetic-rubber gasket is automatically compressed by tightening the flange nut in the ordinary way, this compression causing the inner diameter to become smaller and to grip the pipe. Few details and drawings. *Flight*, November 9, 1939, page 384, 2 illus.

Parachutes

Check Your 'Chute. D. Gold. Instructions on the care of parachutes. *Western Flying*, November, 1939, pages 16–17, 3 illus.

Materials

The National Physical Laboratory. Research in the Physics Department is described including: heat; international-temperature scale; temperature of liquid steel; thermal properties of metals, insulating materials, and refrigerants; radiology; measurements of intensity and protection; and X-ray analysis of zinc oxidation and lead. Continued. *Engineering*, October 20, 1939, pages 433–435, 4 illus.

Metals

Riveting and Welding of Light Metals—Recent Trends of Development in Germany. E. von Rajakowics. Explosive rivets, and the Weibel process of welding light alloys in particular, are discussed. Rivets of Duralumin 681-H, developed by Duerener Metallwerken, can be worked without previous heat treatment in a fully age-hardened condition. When these rivets are hammered, since no disturbance of age-hardening processes can occur, shear strength rises by about 1.27 tons/sq.in. as a result of cold working. Hammered rivets show a minimum shear strength of 15.24 tons/sq.in. Experiments with rivets of Duralumin 681-H and Duranalium MG-5 set in Duralplat sheet and exposed to corrosion test in an agitated bath, showed the 681-H rivets were not attacked due to the protective coating, while those of MG-5 were perceptibly attacked. As introduction of charge and actual explosion is only permissible for rivets in the fully aged condition, Duralumin 681-H is particularly suitable for explosive rivets. Efforts are now being made to increase permissible working time at room temperature for rivets of the Al-Cu-Mg group, by alteration of composition, but such increase is usually at the expense of shear strength. Drawing shows explosive rivet covered by German patent No. 655,669.

Weibel process for fusion welding of light-metal sheets is being widely used, especially for aluminum forging alloys. Process is best suited to welding of light-metal sheets having a thickness between 0.008 and 0.06 in. Edges of sheet are usually flanged as for gas welding. Electrodes, current supply, welding fluxes, position of electrodes, and results of tests of the Duerener Metallwerke are described in great detail. From "Zeit. fuer Metallkunde." *Metal Industry*, October 27, 1939, pages 369–372, 4 illus.

British Standard Specifications. Phosphor bronze sheet and strip; welding and cutting nomenclature, definitions and symbols; test code for fuel-fired furnaces for heating and heat-treatment purposes; and the tension-rod type of turnbuckles. Brief abstracts of specifications. *Aircraft Engineering*, October, 1939, page 401.

Engineers Accent Superior Qualities. Problems of producing higher quality base materials and speedier methods of determining qualities of metals during processing. Papers presented at the A.I.M.E. meeting in Chicago are reviewed. The Carbanalyzer developed by H. K. Work and H. T. Clark is described and illustrated. Desulphurization of pig iron, large-scale desulphurization tests, iron-ore reduction under pressure, and the influence of various alloying elements on the properties of rolled magnesium alloys discussed. *Iron Age*, November 2, 1939, pages 53–56, 2 illus., 3 tables.

Corrosion and Protective Coatings

High Speed Copper Plating. F. F. Oplinger. Details of the development of a process for cyanide solutions, including: anode-cathode efficiency tests at elevated temperatures; anode passivity; effect of carbonate; effect of NaCl, Na_2SO_4, and $Na_2S_2O_3$ on anode and cathode efficiencies of high-temperature solutions; production of bright deposits; and improving physical characteristics. Concluded. *Metal Industry*, October 27, 1939, pages 375–377, 11 tables.

Primers for Non-Ferrous Metals. I. Results of tests on non-ferrous alloy sheet including: Dowmetal E, M, and H; and aluminum alloys 2S, 3S, 4S, 17S, 24S, and 52S. Alclad was not included. Heat treatment, surface treatments, primers, and testing methods are described. *Paint, Oil & Chemical Rev.*, November 9, 1939, pages 60–62, 1 table.

Iron and Steel

Properties of Brazed 12% Chrome Steel. F. C. Kelley. Brazing of stainless steel requires considerable skill. Results of an investigation by General Electric engineers are described. First issue shows how such alloys may be brazed to give tensile strengths up to 140,000 lb./sq.in. Original tests, structure of the joint, strength when heat treated, and strength at 900°F. are discussed.

Second issue—Data on impact tests, shear and fatigue tests on brazed joints, and an explanation of the high tensile strength of the brazed joint. *Iron Age*, November 2 and 9, 1939, pages 33–35 and 34–35, 5 illus., 10 tables.

Tensional Effects of Torsional Overstrain in Mild Steel. H. W. Swift. Experimental work undertaken to ascertain the effects of severe torsional overstrain on the tensile properties of mild steel. In rolled mild-steel bars of good commercial quality in the fully annealed state, the inception of plastic flow is affected by the internal stress distribution as well as the general "scalar" condition of the material as measured, for example, by its hardness number. The relationship between shear stress and shear strain in the plastic region is not independent of the system of applied stress. The plastic stress-strain relationship under tensile conditions, although affected in its

earlier stages by previous strain history, becomes independent of this as straining proceeds. Rupture may be caused by tensile stress, by shear stress, or possibly by a combination of tension and shear. Resistance to rupture by shear stress is modified directionally by overstrain. No positive evidence is furnished regarding the effect of overstrain on resistance to rupture by tensile stress, but there are indications that any such effect is small. Neither strain energy nor hardness is a controlling factor in regard to rupture, nor does either of these quantities define the resistance of the material to plastic strain in the general sense. The reversal of torsional strain has certain remedial effects on the apparent shear strength under tensile conditions, due possibly to the masking of directional properties.

Conditions of rupture, scheme of experimental work, flow curves for tension and torsion, tension after torsion, true stress-strain curves, torsion following tension overstrain, and effect of reversed torsion are discussed in detail. Iron and Steel Institute paper. *Engineering*, October 20, 1939, pages 453–456, 5 illus., 3 tables.

METAL WORKING

Tools for Deep-Drawing and Pressing. J. D. Jevons. First issue—Advantages of cast iron as a tool material; the usefulness of chromium in the form of an electrodeposited coating on the tool in deep-drawing practice; and precautions to be observed in chromium plating.

Second issue—Uses of wood, soft metals, cast bronze, nickel-chromium alloys, and rubber as die materials for drawing and pressing. Ordinary cast bronze is used with excellent results for deep drawing aluminum, and special bronzes offer a fruitful field for experiment. Continued. *Metal Industry*, October 13 and 20, 1939, pages 331–334 and 355–357, 5 illus., 1 table.

NONFERROUS ALLOYS

Production of Magnesium-Alloy Aircraft Parts. L. B. Grant, Dow Chemical Company. Progress made in the use of magnesium alloys in aircraft construction, and problems encountered by aircraft manufacturers in the production of airplane parts made from these alloys. Composition of magnesium alloys for sand and permanent-mold castings are shown in a table and are correlated with the corresponding Army Air Corps and Navy aeronautical material specifications. Processes in producing these castings are described in detail. Surface treatments for protection against salt-water corrosion are discussed, with a comparison showing increased efficiency of Dow No. 7 over the chrome-pickle treatment. Production of die castings, forgings, extruded bars, shapes, tubing, and sheets are also considered with tables of composition, characteristics, and mechanical properties. A-N specification numbers of suitable primers and finish coats for magnesium alloys are listed. *S.A.E. Preprint for National Aircraft Production Meeting*, October 5–7, 1939, 16 pages, 9 tables, long abstract. *Iron Age*, November 2, 1939, pages 36–39, 3 tables.

Centrifugal Casting of Light-Metal Cylinders with Hard Bearing Surfaces. Method employed by Fichtel and Sachs A.-G. for casting light-metal aircraft-engine cylinders is described. From "Zeitschrift Aluminium," July. *A.T.Z.*, September 25, 1939, page 505, 1 illus.

Nida-Bronze. Mechanical and physical properties of Nida-Bronze in tube and rod forms, and as torpedo material. Data are given in tables and discussed, including: hardening stages; modulus of elasticity; heat resistance; Brinell hardness at various temperatures; bearing properties; wear resistance; stress removal; tolerances; chemical properties; and field of application. Load diagram and other curves, and the structure of Nida Bronze are illustrated. Information released by the Vereinigte Deutsche Metallwerke, A.-G. *V.D.I., Supplement*, October 14, 1939, 7 pages, 9 illus., 7 tables.

Age-Hardening Magnesium Alloys. W. F. Chubb. Although the casting properties and corrosion resistance of the alloys of the lithium-magnesium system are noteworthy, it appears doubtful, so far as the binary system alone is concerned, whether any members of this group will prove of any great structural or engineering interest. Lithium-magnesium diagrams are illustrated and discussed, and mechanical properties of the alloys are described. *Light Metals*, October, 1939, pages 342–343, 3 illus., 2 tables.

Metal Spinning in Aluminium. P. S. Houghton. Tools and procedure are described. *Light Metals*, October, 1939, pages 337–339, 11 illus.

Rhodium Plating. A. Bregman. Properties, applications, plating practice, and costs of rhodium. *Iron Age*, November 9, 1939, pages 31–33, 2 illus.

RIVETING

Preventing Creepage in Riveting. Mosers' locating pin developed by Short Bros., Ltd., is designed to hold together sheets and other members to be riveted. Pins are said virtually to eliminate creepage and to be inserted and extracted easily. They are made for $^{3}/_{32}$-in., $^{1}/_{8}$-in., and $^{5}/_{32}$-in. rivets. Brief reference and drawing. *Aeroplane*, October 26, 1939, page 526, 1 illus.

TESTING OF METALS

Determining Film Thickness with the Recording Spectrophotometer. E. Q. Adams and L. S. Ickis, Jr. Recording spectrophotometer simultaneously affords a permanent record of the film thickness and the reflecting characteristics of the material. Application of the method to the transparent oxide coatings electrolytically applied to aluminum by the Alzak process is described. *General Electric Rev.*, October, 1939, pages 450–451, 4 illus., 1 table, equations.

Electrical Methods of Metal Testing. Instruments developed for measuring fatigue value, hardness, thickness of foil, and thickness of metal layers. *Metal Industry*, November 3, 1939, pages 391–392, 1 illus.

A Modern Swiss Research Laboratory. A. von Zeerleder. Research laboratories of the Société Anonyme pour l'Industrie de l'Aluminium at Neuhausen, and some of the equipment for materials testing, investigation of foundry alloys, and metallurgical department. *Metal Industry*, October 13, 1939, pages 325–328, 11 illus.

Small Equipment for Mechanical Testing. Significance of the notched-bar test, and the theory and practice of testing by slow bonding in the Tensometer are discussed. The "balanced impact" and 5-ft.-lb. impact machines are described. Photographs and drawings include: chucks for the notch-bar tests and dimensions of the small notched-bar test piece; planimeter specially designed to measure area of the notched-bar diagram obtained with the slow-bend test; tools utilized in the rapid and accurate production of the notch in the slow-bend test; method of plotting the notched-bar diagram with the Hounsfield planimeter; "Balance Impact" machine; and a machine for use where insufficient material is available for the employment of the standard test piece, and the special notching machine employed in conjunction with it. Continued. *Light Metals*, October, 1939, pages 340–341, 8 illus.

Pendulum and "Cloudburst" Methods of Measuring and Testing Hardness. S. R. Williams. When Kusnezow devised and used the pendulum hardness tester he made the length of time required by a material to decrease the initial amplitude of vibration down to a determined value serve as a hardness index. Rehbinder followed continuously the decrease in amplitude with time. The author believes that Rehbinder has initiated an important series of researches which it would be desirable to continue. He refers to the study of hardness made by W. A. Wesley and considers that his experiments as well as those of Rehbinder offer a fruitful field of research. He suggests that instead of Rehbinder's pendulum it would be of interest to test these hardness depressers by means of the Microcharacter.

The Kusnezow pendulum hardness tester, and the Herbert Cloudburst process are described. Concluded. *Instruments*, November, 1939, pages 301–303, 4 illus.

Rubber

A Visit to the Wondergrip Factory. Some of the nonslip, noncombustible synthetic materials used in aircraft are mentioned. These materials are resistant to oil, gasoline, steam and acid, are compressible without displacement and are nonporous, do not absorb solvents, are good insulators and, because of their two-phase composition, are good vibration dampers. Aeromat for wing walkways, Elaical, Polycel and Aerocel jointings for oil, steam and hydraulic joints, and Kalorcel for pressure purposes, a new locknut, and testing laboratories are referred to. A wind tunnel for icing experiment, and other equipment are illustrated. *Aeroplane*, October 12, 1939, pages, 464–465, 5 illus.

Bearings

Low Lead-Silver Alloys for Bearings. R. W. Dayton. Bearings of 3- to 4- percent Pb-Ag alloys are highly resistant to seizure and have the physical properties which enable them to carry high loads without mechanical failure. Electrodeposition is shown to be the best method of bonding Pb-Ag alloys to steel. Engine tests of Pratt and Whitney and Allison Engineering Company have proved that silver-base alloys have great promise for use in highly stressed bearings. Preparation of alloys, bearing properties, corrosion resistance, physical properties, structure, and lining methods are described.

A supplementary note gives test results which were obtained with electrodeposited silver-lead alloys on a machine simulating the action of an engine. Two full-size silver master-rod bearings were prepared at Pratt and Whitney for electroplating. Table shows seizure resistance of various bearing materials as determined in the Pratt and Whitney engine type of bearing tester. *Metals & Alloys*, October, 1939, pages 306–310, 324, 10 illus., 4 tables.

Sintering of Copper and Tin Powders. H. E. Hall. Structural stages in producing a porous bronze bearing from copper, tin and graphite powders are described. Colored photomicrographs show the evolution of an alloy from discrete metal particles. *Metals & Alloys*, October, 1939, pages 297–299, 6 illus., 2 tables.

Leaded-Bronze Bearing Alloys. Recommendations of the I.B.F. Non-Ferrous Sub-Committee. Tables show: the three compositions of leaded bronze selected for bearings and composition of the B.S.S. 421 alloy; results of mechanical tests on three leaded-bronze bearing alloys and on a modified composition of alloy L.B.2; and recommended composition and mechanical properties to be specified for the three leaded-bronze bearing alloys. Results of study are discussed and the percentage of nickel to be allowed in these leaded bronzes is explained. Report presented before International Foundry Congress. *Metal Industry*, October 20, 1939, pages 350–352, 2 illus., 4 tables.

Fuels and Lubricants

The A.P.I. Hydrocarbon Research Project. D. P. Barnard. Preparation of as many gasoline-range hydrocarbons as possible and examination for their basic engine-combustion characteristics, and physical, thermal and other properties are the objects of the project initiated September 1, 1938. Engine studies consisting of conventional A.S.T.M. and C.F.R. research ratings, plus the determination of permissible critical compression ratios under four widely varying conditions of service are being conducted by the General Motors Research Laboratories. Critical compression ratios are to be determined over a wide severity range which includes conditions less severe than the C.F.R. research method to a set of conditions demonstrated to be more severe than those ordinarily encountered in aircraft practice. Basic plan is to map the gasoline-range field as thoroughly as possible for the purpose of providing a background for any specialized development work.

Procedures employed for the engine studies are discussed, including: general problem of knock measurement; conventional A.S.T.M. and C.F.R. research knock tests; development of procedure for additional knock tests; critical-compression-ratio tests and standardization of engine and test procedure for these tests; and comparative tests between different engines and different methods of test. Data already obtained on certain hydrocarbons are given.

General program, work accomplished in hydrocarbon preparation at Ohio State University and procedures adopted, and general plans for determining physical and thermal properties are also described. *Oil & Gas Jour.*, November 17, 1939, pages 117–118, 122, 124, 127, 128, 9 illus., 2 tables.

Catalytic Desulfurization to Improve Aviation Blending Naphthas. W. A. Schulze and R. C. Alden. Experimental investigation has shown that the tetraethyl-lead response of aviation gasolines consisting of blends of isooctane base and straight-run naphtha of either refinery or natural gasoline origin may be markedly improved by removal of sulfur compounds from the naphtha. Practically complete desulfurization has been obtained by treatment of the naphtha vapors over a bauxite catalyst at temperatures of 700° to 750°F. Since desulfurized blends have greater lead response, the minimum percentage of isooctane required in high-octane gasoline may be appreciably reduced.

It is possible, therefore, to increase production of high-octane gasoline without a corresponding increase in isooctane base. If desired, hydrocarbon composition of the blend may be left unchanged and a higher octane gasoline be produced as a result of improved lead response. In the case of Hobbs pentane-free natural gasoline, production of high-octane blended and ethylized aviation gasoline for a given amount of isooctane was increased as follows: 92-octane number with 0.5 cc. TEL—19.7 percent; 100-octane number with 3.0 cc. TEL—27.7 percent; 87-octane number with 1.0 cc. TEL—52.2 percent.

Effects of sulphur on lead response, catalytic desulphurization of components of 100-octane gasoline, and blends of isooctane with undesulfurized and desulfurized naphthas (Borger "pentane-free" natural gasoline), and New Mexico straight gasoline are also discussed. *Oil & Gas Jour.*, November 17, 1939, pages 199–200, 202–204, 4 illus., 6 tables.

High-Octane Aviation Fuel by the Sulfuric-Acid Alkylation Process. Process affects directly the union of isoparaffins with olefins in approximately equal volumes to form branched-chain paraffins in the presence of strong commercial sulfuric acid as a catalyst and in a single-stage operation. With sufficient isoparaffin, potential yields of branched-chain products by alkylation from a given refinery stream are more than double those obtainable by the two-stage process of olefin polymerization followed by hydrogenation. Principles of operation; feed stocks; effects of operating variables (isoparaffin-olefin ratio, contact time, acid strength, temperature, acid-hydrocarbon ratio, olefin concentration of the feed, agitation); characteristics of the product; acid requirements; and commercial aspects. Contribution by the Anglo-Iranian Oil, Humble Oil and Refining, Shell Development, Standard Oil Development and Texas companies. *Oil & Gas Jour.*, November 17, 1939, pages 104–108, 9 illus., 5 tables.

Methane as Fuel. J. P. Lawrie. Most powerful aircraft engines would run successfully on methane as a fuel and, because of the high equivalent octane number of methane, could be made to give even more power than on 100-octane gasoline, according to the editorial note preceding the article. Drawback has been the weight and size of containers. A quotation from the 1938 report of the Aeronautical Research Committee states that methane could be used without detonation in engines under very high-duty conditions, and that the possibility of producing a suitable container has been examined by the Royal Aircraft Establishment, an experimental tank having been constructed and tested.

The article itself points out the abundant supply of methane available, its properties, advantages over gasoline, and containers. *Aeroplane*, November 2, 1939, page 549.

Petroleum for Germany at War. B. T. Brooks. There is abundant evidence that Germany's motor and aviation fuel needs have been well studied. It is estimated that all of Germany's fast pursuit airplanes and faster bombers operate on high-octane gasoline and that some of the heavier bombers and the converted transport airplanes, comprising probably 20 percent of the entire air force, operate on Diesel power. An unknown number of airplanes have been adapted to use benzene blends, by water cooling, thus enabling them to use some 4,500,000 barrels of benzene for aviation purposes. It is also known that some of the newer types of motors use the forced injection method, which is also used in Diesel engines, thus enabling them to use gasolines of a wider range of octane and volatility characteristics to much greater advantage.

Germany's situation with respect to motor fuels and high-octane aviation fuel is reviewed, including: supply of basic raw material; technical preparation, such as adaptation of engines to utilize all available types of fuels; and manufacturing equipment to produce high-octane and other types of fuel. *Industrial & Engineering Chemistry, News Ed.*, November 10, 1939, pages 679–680.

Engine Design and Research

Gas-Exchange Process and Limitations of the Valve-Four-Stroke Timing for Aircraft Engines. F. R. Schmidt. Means of obtaining increased output per liter vary with regard to effect of reciprocating movement of the column of gas. Supercharging alters the reciprocating gas movement, which limits r.p.m. Means offered by the four-stroke cycle with poppet valves for keeping small the losses in the reciprocating movement of the gas, are similar in the two cases. Both increase in r.p.m. and supercharging require, besides maximum cross-sections of inlet opening, greater inlet timing periods. Owing to lower mechanical stresses and smaller forces in the valve-operating mechanism, this allows limits in r.p.m. to be further extended. Explanation is still lacking for variation of best ratio inlet section/outlet section, with valve lift diagrams such as are required for high-speed engines and therefor low volumetric efficiency. Research is required with these diagrams to explain the influence of the warming of the live gas and the volumetric efficiency on the blower performance. Knowledge of these relationships is made more difficult to obtain by the large number of influential factors in raising r.p.m. and this work therefore extends to include them individually.

Tests were undertaken with cylinders of from 0.5 to 4.0 liter capacity. Mean gas velocity may be taken in its simplest form to provide a good general survey of valve-lift diagrams of high-speed engines. To demonstrate the influence of the valve spring, a calculation value "the spring stress" was established—the product engine r.p.m. × valve-lift = constant with the alternating load range as parameter. By means of this spring stress, r.p.m. limits were determined for various cylinder sizes as well as for cams developed by the D.V.L.

It was shown that r.p.m.'s are obtained today which approach the limit h.h. = 3100, but the D.V.L. cams allow r.p.m.'s which presuppose very well designed driving gear, the limits for push-rod operation being finally exceeded. Cylinders of less than 1-liter capacity with overhead camshafts must have the most carefully balanced operating mechanism, as at approximately 16.5 meters/sec. piston speed, they reach at the same time the limits for the valve spring, for the cross-sectional port area, and for the overhead camshaft. Larger cylinders allow somewhat higher piston speeds. Importance of the development of the Burt sleeve again comes to the fore, as this permits simple production, maintenance, and low initial costs. Long abstract. *Aircraft Engineering*, October, 1939, page 391. Complete article, *Luftfahrtforschung*, May 20, 1939, pages 251–275, 61 illus., 3 tables, 25 equations.

Investigation of the Gas-Exchange Process of Various Valve Timings and the Attainable Limiting Values of Compression Ratio, B.M.E.P. and Effective Fuel Consumption. T. Hoock. Performance of larger aero engines is limited by mass of the charge admitted during the induction stroke and by the tendency to knocking, which generally commence at the hot exhaust valve. A considerable increase in performance is possible if valve operation is used which offers less resistance to the path of the gas and allows greater volumes to pass through. Walls of the combustion chamber must remain at a lower temperature, as uniform as possible, in order to secure knock-free operation at higher compressions. Since tests show that freedom from knocking and piston pressure of rotary-valve engines are greater than with similar engines with poppet valves, test results were used to determine the attainable limit values for compression ratio, mean piston pressure, and specific fuel consumption of large-dimension aero engines. Short abstract. *Aircraft Engineering*, October, 1939, page 391. Complete article. *Luftfahrtforschung*, May 20, 1939, pages 276–282, 8 illus., 3 tables.

Low-Drag Engines. The twenty-cylinder multi-bank radial aircooled engine is proposed as the ideal design for engines in the 1600- to 2000-hp. category. Installation would be not unlike that of the engine in the new Curtiss P.42 fighter, but the extension shaft might not be more than a foot long. Cooling would be the same as for 4-cylinder inline engines. Flush-fitting exhaust collector chamber of rounded D-section would follow the contours of the cowling, one ejector stub being used for each. Two collector chambers above the horizontal center line would serve eight cylinders each, and the third, below and to the side, the four inverted cylinders. Proposed dimensions and outputs (1950 hp. at 3000 r.p.m. for take-off) are given. It is considered that the installation would have a lower drag/hp. than that of the Double Wasp. Installation in the Curtiss P.42 is said to make a very strong case for the retention of aircooled engines even in fighting planes. "From your illustration" of the P.42 "the air-scoop of this engine would appear smaller than for an inline liquid-cooled motor of similar power." Letter to the editor.

A model of a six-row 36-cylinder engine with cylinders set helically and not parallel to the crankshaft is illustrated. It is the design of an Italian engineer, Signor Innocenti. *Flight*, November 9, 1939, page 380, 1 illus.

Pressure Calculations for Oil Engine Fuel-Injection Systems. E. Giffen and A. W. Rowe. Method of calculation described is used in determining pressure variations in the normal fuel-injection system. Besides dealing with the transmission of pressure impulses from one end of the pipe to the other; the method includes those modifying conditions present in an actual system, namely capacity effects at the pump and at the nozzle, action of the pump delivery valve, and varying conditions in the spring-loaded injection valve. Results of a calculation on a typical injection system, and a diagram of nozzle pressure obtained experimentally from the same system are included and agree so well that the treatment may be regarded as giving a very close approximation to actual conditions in the injection system. *Instn. Mechanical Engrs., Jour.*, October, 1939, pages 519–531 and (disc.) 531–534, 6 illus., 8 tables, 14 equations.

Recent Developments in High-Speed Oil Engines. S. J. Davies. Developments since the author's paper to the Institution in 1932 are reviewed under the subdivisions of combustion-chamber design, injection systems, and fuels. While few novel features can be reported under combustion-chamber design, the growth of knowledge concerning injection systems and the properties of fuels has been considerable. Processes in fuel-injection systems and conditions governing breakup of fuel sprays are reasonably clear. Fundamentals of combustion and what determines ignition lag still remain obscure. Interaction of breakup of spray and course of combustion are also indefinite, and trial-and-error methods must still be employed. The cetane scale for assessing the suitability of fuels has been introduced. Reference is made to electrical indicators and determination of impact loading on running gear during combustion. Two-stroke working and supercharging are discussed. *Instn. Mechanical Engrs., Jour.*, October, 1939, pages 535–547, 10 illus.

Some New Investigations on Old Combustion-Engine Problems. G. Eichelberger. Experimental work on heat flow in cylinder walls and pistons, including: measured temperature distribution in Diesel engines; arrangement of thermocouples; heat transfer to the cooling liquid; temperature of the working gases; resulting mean temperature for heat flow; periodical heat flow; measured temperature fluctuations model test of thermocouples to determine depth at which thermocouples will indicate the temperature if they make metallic contact with the wall at a depth of 1/100 in.; and periodical rate of heat transfer. *Engineering*, October 27, 1939, pages 463–466, 24 illus., equations.

The Prospects of C.I. Engines. A. W. Morley. Difficulties which block the road to high performance in the compression-ignition engine are discussed. Three main directions are described along which it is possible to increase the output per unit of cylinder volume, including: development of various types of two-stroke engine, using scavenging pressures attainable with blowers of existing design; development of highly boosted four-stroke engine to boost pressures as high as practicable from considerations of thermal efficiency; and artificial methods of increasing output. Among the artificial methods which have been suggested, the most important is to enrich the air supply by adding oxygen to it. Possibility of doing this is considered, and two-stroke development and the highly-boosted four-stroke engine are discussed in detail. *Aircraft Engineering*, October, 1939, pages 380–382, 2 illus.

The Sticking of Piston Rings in an Aircooled Two-Cycle Engine and the Effect of Various Precautions. W. Gebhardt. Regardless of blower cooling the sticking of piston rings in the 500-cu.cm. air-cooled two-cycle engine could not be avoided by any of the described arrangements, but only retarded. Endurance runs were made under difficult conditions with 22–23-hp. output per liter, to attain a shorter basis of comparison. Compared with normal practical operation in the vehicle, operating periods were obtained, up to the limit of its capacity, which were considerably longer but comparable.

In the case of normal light-metal pistons, axial play of the rings in the grooves showed an influence. Approximately 0.1 was optimum while additional enlargement showed no improvement but was rather unfavorable. Small clearances (0.04 to 0.05) were entirely incorrect for large pistons on water-cooled four-cycle engines. Ring tension showed very slight influence. An improvement was brought about by the three-ring arrangement with rings of 4-mm. axial depth, compared with those of only 2.5 mm.

A ring support developed as a hard guide edge showed an advantage with a ring of 6-mm. axial depth. A standard ring in the support, a double ring, and a cleaner ring did not yield such good results.

A throat introduced in the front of the ring in the form of a collar yielded very good results. A guide ring used in the same manner, because of the small size required could not be made stiff enough. An additional simple and inexpensive means in the form of a "trapeze" ring, developed at the Mahle testing center, could have been combined with the simple arrangement described in the second paragraph more effectively than those described in the third and fourth paragraphs, but was not known at the time the tests were made. *A.T.Z.*, September 25, 1939, pages 502–505, 11 illus., 1 table.

Engine Manufacture

Design Problems in the Quantity Production of Aircraft Engines. H. C. Hill, Wright Aeronautical Corporation. Some of the design developments which have helped to overcome difficulties in the operation of the engines and in the production of 50 to 300 engines per month are discussed. The very marked influence of design in improving the oil-circulating system is illustrated, and the oil-circulating system of the Cyclone engine is taken as an example. Results of experiments on crankcase scavenging, sump scavenging, piston lubrication and cooling, and factors controlling the amount of oil flow in the crank chamber are described in detail. *S.A.E. Preprint for National Aircraft Production Meeting*, October 5–7, 1939, 17 pages, 5 illus.

Engine, Fuel and Lubricant Testing

Effect of Operating Conditions on Piston-Ring Sticking in Continuous Testing of Fuels. W. Glaser. By means of continuous testing on a liquid-cooled single-cylinder engine under high thermal load, the effects of the different operating conditions on the operating period up to piston-ring sticking were investigated. Effects are discussed in the order of their importance. The unsuitability of breaking in the piston ring in such tests is pointed out, and it is shown how results of endurance-test runs which are not clear can be corrected. From the test results the conclusion is reached that operating periods depend on three basic conditions: fuel, lubricant, and temperature in the piston-ring portion. On the basis of such knowledge

new trends are suggested by which possibly the problem of residue formation and lubricating power may be further clarified.

Test materials and test procedure are described in detail. Test results are discussed including: side play of the piston ring; cooling temperature; combustion-chamber temperature; fuel consumption; output; r.p.m.; oil pressure; oil temperature; compression; piston play in the cylinder; and cylinder, piston, and ring materials. D.V.L. report. *Luftfahrtforschung*, August 20, 1939, pages 438–446, 13 illus.

Oil Frothing and Bearing Durability. Object of a research recently started by the Institution of Automobile Engineers is to study the problem of oil frothing as experienced in aircraft engines. An apparatus has been developed in which a gear pump draws oil from an electrically-heated tank, and at the same time air is admitted through a calibrated orifice gage and a variable needle valve in the suction line. Methods of measuring the frothiness of the oil are being developed, a study of the flow of frothy oil through bends and pipe junctions is being made, and methods of deaerating frothy oil are also being examined. It is proposed to study the effect of frothiness on the durability of bearings using a newly-designed machine. A few details of this machine, and of apparatus for studying oil frothing are given. Short note. *Engineer*, October 27, 1939, page 433

Recent Methods of Fuel Testing. F. Seeber. Determination of detonation tendency of aircraft-engine fuels with high resistance to detonation according to the octane-number method in the C.F.R. engine used today is unsatisfactory and based on incorrect assumptions. The present single-point test methods are discussed briefly, the importance of determination of the beginning of detonation for the octane number is pointed out, and suggestions are made for the improvement of detonation testing in C.F.R. engine. The difficulty of the transfer of results obtained in the detonating test engine to the single- and multi-cylinder aircraft engine, however, is not solved therewith.

The D.V.L. supercharging testing method developed has the advantage of determining the detonation tendency of fuels directly in each aircraft-engine single cylinder, without structural changes being involved. This method is described and advantages of a multi-point method are discussed. With the possibility that test conditions of the supercharging method approach conditions of aircraft operation rather closely, a diagrammatic presentation of the detonating properties is possible, which is of great importance for the further development of high-speed aircraft engines and their fuels. D.V.L. report presented at the Lilienthal-Gesellschaft fuer Luftfahrtforschung, February 17. *Luftfahrtforschung*, August 20, 1939, pages 431–437, 16 illus.

The Measurement of Compression Pressure as a Measure of the Condition of Engine Cylinders. H. Fiebelkorn. By checking the pressure at the end of the compression stroke with a simple measuring apparatus, the technician is in a position to judge the condition of tightness in each engine cylinder. It is then possible to localize a defect and to obtain a better opinion as to the time for overhauling or repairing cylinders, pistons and valves. Measurements of pressure at the end of compression at various compression ratios and r.p.m., at various valve clearances and r.p.m., with starting r.p.m. at various valve clearances, and pressure measurements of various engine cylinders are shown in tables. Apparatus is illustrated and discussed. *A.T.Z.*, September 25, 1939, pages 506–507, 2 illus., 5 tables.

Temperature Indicating Paints. Recent advances made in Germany in developing stable paints for use at high temperatures. The I. G. Farbenindustrie Akt.-Ges. in connection with their fuel-research work at Oppau have found it desirable to undertake extensive investigation with a view to finding temperature-indicating paints which could be applied under more drastic and exacting conditions than those envisaged by earlier workers. No less than 300 different compounds, mostly metal salts, have been investigated at Oppau, but the search for other materials is being continued, for use at still higher temperatures up to 650°C. Importance of the time factor and the duration of heating, choice of a suitable binding agent, application to aero-engine cylinders and pistons where it is of particular value in indicating the best positions for positioning of air ducts and baffles, and results of a detailed study made of a cylinder of the B.M.W.132 engine are discussed. *Aircraft Engineering*, October, 1939, pages 385–386, 4 illus., 1 table, 2 plates on sup. sheet.

Engines

The Hispano-Suiza 14-AA and 14-AB 14-Cylinder Engines. Output of the 14-AA double-row radial air-cooled engine surpasses 1100 hp. while the previously rated output of 600 hp. of the 14-AB can be raised to 760 hp. These increases of output resulted principally from research on the cooling and the use of cylinder heads having large ribs. For the 14-AA-12: bore 155.6 mm.; stroke 170 mm.; output at ground level 985 hp., for take-off 1080 hp., and at 4000 meters 1150 hp.; fuel consumption 265 gr./hp.-hr. For the 14-AB-12: bore 135 mm.; stroke 130 mm.; output at ground level 725 hp., for take-off 800 hp.; and at 650 meters 745 hp.; fuel consumption 255 gr./hp.-hr. Long description and complete characteristics and performances for the 14-AA-00, 14-AA-02, 14-AA-04, 14-AA-06, 14-AA-10, 14-AA-12, and the 14-AB-02, 14-AB-10, and 14-AB-12 engines. *L'Aérophile*, August, 1939, pages 182–184, 2 illus., 1 table.

Parts and Accessories

Modern Methods of Conditioning Lubricating Oil During Use. C. A Winslow. Results of many years of designing, building, and testing lubricating systems for internal-combustion engines. Design of various types of filters are briefly reviewed. Results of actual tests, both field and laboratory, as well as what happens to engines, filters, and lubricating oil during normal automotive service are discussed in detail. *S.A.E. Preprint for National Tractor Meeting*, September 28–29, 1939, 14 pages, 13 illus.

Carburetor for Light Aircraft. Marvel-Schebler Model MA-3 carburetor, now standardized on Franklin air-cooled engines, is an updraft carburetor of the plain-tube fixed-jet type, having a double float mechanism to provide accurate and continuous fuel metering under all flight attitudes. Short description and drawings showing operating parts. *Aero Digest*, November, 1939, page 116, 1 illus.

The Ceco Fuel Pump. Ceco aircraft fuel pump, a rotary-vane-type engine-driven unit, is now available in capacities of 225, 425, and 800 gal./hr. at 2500 r.p.m., with relief-valve pressures of 2 to 12 and 2 to 28 lb. Pressure may be set to any desired value within the pump range by adjustment of the knurled screw on the valve cover. This maintains a uniform discharge pressure throughout a wide variation in intake suction, discharge rate, and pump speed. Short description. *Aero Digest*, November, 1939, page 116, 1 illus.

For Valve Adjustment. Bado valve-clearance adjuster, patented by F. J. Bado, provides an adjustment in the length of the tappet or pushrod to equalize clearances when the engine is hot or cold. Tappet is formed of two parts, the outer ends of which engage the valve-operating cam and the valve rocker arm, respectively. Short note and drawings. *Aeroplane*, November 9, 1939, page 588, 3 illus.

Meteorology

Aviation Wind Forecasts over the Pacific. J. A. Day. Effect which the thermal field, existent at any particular time within an air mass, would have on the wind direction and velocity at levels above the gradient level, as applied to airline work by Vernon and Ashburn, is considered. Degree of success attained in the effort now being made by the Pacific Division Meteorological Department of Pan American Airways to apply the principles of thermal wind component and to obtain results of practical value for use in making upper-wind forecasts over extensive ocean areas is discussed. Procedure used in the determination of the thermal field over the Pacific, and methods of attack for its application to forecasting are discussed. *Bul. Am. Meteorological Soc.*, October, 1939, pages 340–345, 7 illus.

A Diagram for Obtaining in a Simple Manner Different Humidity Elements and Its Use in Daily Synoptic Work. W. Bleeker. Construction of the diagram; determination of humidity elements from ventilated thermometers at approximately mean sea level; some theoretical applications; application of the diagram for nightfrost- and radiation-fog forecasting; and transformation of the diagram. *Bul. Am. Meteorological Soc.*, October, 1939, pages 325–329, 1 illus., 6 equations.

Certain Statistical Relationships Bearing on the Preparation of Five-Day Weather Forecasts in the United States. H. C. Willett. Some of the leads followed, and tentative conclusions reached in an attempt to formulate a basis for the preparation of five-day weather forecast at M.I.T. An attempt was made to initiate a statistical check as to the extent to which anomalies of temperature and precipitation for the five-day forecast periods may be correlated with those features of the general circulation which might be expected to affect the individual forecast regions; and to find some basis for forecasting important changes in the general circulation. Temperature as an element correlates more closely with the mean state of the general circulation, as given by mean pressure distribution, than does precipitation. The most successful lead in forecasting significant changes in the general circulation pattern, developed by Rossby on the basis of a recent paper by J. Bjerknes, is explained. *Bul. Am. Meteorological Soc.*, October, 1939, pages 329–331.

Hurricanes and South Atlantic Circulation. J. de S. Ferraz. Cases of southern highs coinciding with northern hurricanes, and the question of whether a whirl can be created in a momentaneously narrower section of the doldrums, between fresh northeast to eastnortheast currents and the originally south winds already deflected to southwest beyond the 20° N. parallel. *Bul. Am. Meteorological Soc.*, October, 1939, pages 334–335.

Weather and Air Warfare. Sir Gilbert Walker. Reasons for the discontinuance of the publication of daily weather reports and charts in English newspapers. Value of a knowledge of wind velocity, temperature and pressure to the gunner, the effect of wind velocity on flight of airplanes on military missions, and influence of weather on the use of poison gases are pointed out. A forecast of weather in England would be of great value to Germany in determining when a raid should be made, and a forecast of weather in Germany would be useful there when deciding whether preparations should be made in anticipation of a raid from England. Disturbances that determine weather in general travel eastward. For predicting German weather, it is necessary to know not merely conditions over the Atlantic but over England and France. "Hence data that we collect of meteorological conditions to the west of Germany must be prevented from reaching her, and must become virtually contraband." *Aeroplane*, October 12, 1939, page 442, 2 illus.

Aircraft Radio

Radio in Navigation. C. D. Tuska. Historical aspects of radio direction and position finding, technical characteristics of directional radio, and variable errors in radio directions finders. To be continued. *Journal Franklin Inst.*, October, 1939, pages 433–443, 3 illus.

Instrument Landing on 40 Centimeter Waves. C.A.A.-M.I.T. system demonstrated to the C.A.A. at Boston airport is described. Five-mile straight-line glide path is generated with low-power transmitters and horn radiators. *Aviation*, November, 1939, pages 26–27, 78, 5 illus.

Radio Facilities at New York Municipal Airport. Mainstay of radio navigation at North Beach Airport is the new full-power radio range with simultaneous voice transmission and cone-of-silence marker, located 3.6 miles southwest of the airport on the prolongation of the airport's longest runway running SW-NE. Northeast leg of the radio range is oriented directly over this runway for aid in making accurate instrument approaches. Radio range of the latest type, SMBRA-Z, consists of a standard Radio Receptor Type TR-412 400-watt remote-controlled simultaneous radio range, operating from 220-volt power source, consuming 3000 watts, and associated with the TR-412 goniometer unit. Transmitter complement comprises two Radio Receptor Type TR-420 remotely-controlled 25-watt transmitters, one kept as standby equipment. Long description of radio equipment. *Aero Digest*, November, 1939, pages 52, 55, 5 illus. See also *Aviation*, November, 1939, pages 24–25, 6 illus.

United Air Lines Radio Laboratory. H. W. Roberts. Outstanding developments completed by U.A.L. Radio Laboratory during its twelve years are reviewed, and laboratory organization and current work on eighteen major projects involving research, design, and development are summarized. *Aero Digest*, November, 1939, pages 60, 62, 8 illus.

Piloting

Conversion II. Further advice to "anybody who may be called upon quite suddenly to fly an 'advanced type,'" with special references to the Harvard. *Flight*, October 19, 1939, page 314.

Old Dogs and New Tricks. F. D. Bradbrooke. Advice to amateur pilots, chiefly the owner-pilots, who are taking the "conversion course" on how to fly the modern twin-engined types of military aircraft with high wing leading, including the right action before take-off, during flight, before landing, and after landing. Gadgets to be watched, the power-glide approach, and the effect of "G" on stall are discussed. *Aeroplane*, October 19, 1939, pages 472–473.

Aeronautical Personnel

Dealing with the Problem of Personnel. C. S. Mattoon. The aircraft inspectors' responsibility, ratio of inspectors to workmen, distribution of inspectors in a typical manufacturing organization, and the selection of inspectors are discussed. *Aero Digest*, November, 1939, pages 70, 73, 5 illus.

How Teaching Methods Have Changed in Ten Years. Changes in teaching methods at the Boeing School of Aeronautics which has completed ten years of aeronautics instruction. Ten years ago nine months of ground training was sufficient to qualify students for position as co-pilots, but today students go through 24 months of instruction. *U.S. Air Services*, November, 1939, pages 14–15, 28, 3 illus.